VOLUME 16 JULY, 1928 NUMBER 7

PROCEEDINGS

of

The Institute of Radio Engineers

Published Monthly By
THE INSTITUTE OF RADIO ENGINEERS
Publication Office: 450-454 Ahnaip St., Menasha, Wis.

BUSINESS, EDITORIAL AND ADVERTISING OFFICES
33 West 39th Street, New York, N.Y.

Subscription $10.00 per Annum in the United States
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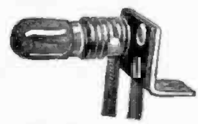

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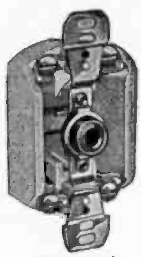

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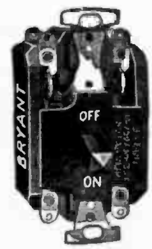

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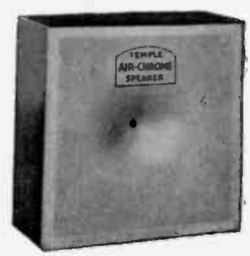

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SUGGESTIONS FOR CONTRIBUTORS TO THE PROCEEDINGS

PREPARATION OF PAPER

Form—Manuscripts may be submitted by member and non-member contributors from any country. To be acceptable for publication manuscripts should be in English, in final form for publication, and accompanied by a summary of from 100 to 300 words. Papers should be typed double space with consecutive numbering of pages. Footnote references should be consecutively numbered, and should appear at the foot of their respective pages. Each reference should contain author's name, title of article, name of journal, volume, page, month, and year. Generally, the sequence of presentation should be as follows: statement of problem; review of the subject in which the scope, object, and conclusions of previous investigations in the same field are covered; main body describing the apparatus, experiments, theoretical work, and results used in reaching the conclusions; conclusions and their relation to present theory and practice; bibliography. The above pertains to the usual type of paper. To whatever type a contribution may belong, a close conformity to the spirit of these suggestions is recommended.

Illustrations—Use only jet black ink on white paper or tracing cloth. Cross-section paper used for graphs should not have more than four lines per inch. If finer ruled paper is used, the major division lines should be drawn in with black ink, omitting the finer divisions. In the latter case, only blue-lined paper can be accepted. Photographs must be very distinct, and must be printed on glossy white paper. Blueprinted illustrations of any kind cannot be used. All lettering should be 3/16 in. high for an 8 x 10 in. figure. Legends for figures should be tabulated on a separate sheet, not lettered on the illustrations.

Mathematics—Fractions should be indicated by a slanting line. Use standard symbols Decimals not preceded by whole numbers should be preceded by zero, as 0.016. Equations may be written in ink with subscript numbers, radicals, etc., in the desired proportions.

Abbreviations—Write a.c. and d.c., kc, μf, $\mu\mu$f, emf, mh, μh, henries, abscissas, antennas. Refer to figures as Fig. 1, Figs. 3 and 4, and to equations as (5). Number equations on the right, in parentheses.

Summary—The summary should contain a statement of major conclusions reached, since summaries in many cases constitute the only source of information used in compiling scientific reference indexes. Abstracts printed in other journals, especially foreign, in most cases consist of summaries from published papers. The summary should explain as adequately as possible the major conclusions to a non-specialist in the subject. The summary should contain from 100 to 300 words, depending on the length of the paper.

PUBLICATION OF PAPER

Disposition—All manuscripts should be addressed to the Institute of Radio Engineers, 33 West 39th Street, New York City. They will be examined by the Committee on Meetings and Papers and by the Editor. Authors are advised as promptly as possible of the action taken, usually within one month.

Proofs—Galley proof is sent to the author. Only necessary corrections in typography should be made. *No new material is to be added.* Corrected proofs should be returned *promptly* to the Institute of Radio Engineers, 33 West 39th Street, New York City.

Reprints—With the notification of acceptance of paper for publication, reprint order form is sent to the author. Orders for reprints must be forwarded promptly as type is not held after publication.

PROCEEDINGS OF

The Institute of Radio Engineers

Volume 16 July, 1928 Number 7

CONTENTS

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The PROCEEDINGS of the Institute is published monthly and contains the papers and the discussions thereon as presented at meetings.

Payment of the annual dues by a member entitles him to one copy of each number of the PROCEEDINGS issued during the period of his membership.

Subscriptions to the PROCEEDINGS are received from non-members at the rate of $1.00 per copy or $10.00 per year. To foreign countries the rates are $1.10 per copy or $11.00 per year. A discount of 25 per cent is allowed to libraries and booksellers.

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Entered as second class matter at the Post Office at Menasha, Wisconsin.

Acceptance for mailing at special rate of postage provided for in the Act of February 28, 1925, embodied in paragraph 4, Section 412, P. L. and R. Authorized October 26, 1927.

Publication Office 450-454 Ahnaip Street, Menasha, Wis.
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Walter G. Cady

MEMBER OF THE BOARD OF DIRECTION OF THE INSTITUTE, 1928

Walter G. Cady was born in Providence, Rhode Island, December 10, 1874. He received the Ph. B. and M. A. degrees from Brown University in 1895–96, and the Ph. D. degree from the University of Berlin in 1900. From 1895 to 1897 Dr. Cady was instructor in mathematics at Brown University. During the period of 1900–02 he was a Magnetic Observer for the Coast and Geodetic Survey. He left this service in 1902 to become an instructor in physics in Wesleyan University at Middletown, Conn. In 1903 he was promoted to Assistant Professor and in 1907 Professor and Head of the Physics Department.

He is a Lieutenant Commander in the U. S. Naval Reserve, a member of the Physical Society, Optical Society, American Institute of Electrical Engineers, and the American Academy of Art and Science.

During the war Dr. Cady was associated with groups at the General Electric Company's Research Laboratory, Columbia University, and the Naval Experimental Station in New London, Connecticut, working on the application of piezo-electricity to the problem of submarine detection.

Dr. Cady has published various papers on cathode rays, magnetic declinograph, electric arc, electric oscillations, piezo-electric resonator and oscillator. In 1923 he made the first direct international comparison of frequency standards by comparing a set of his quartz resonators with frequency standards in Italy, France, England, and the United States.

Dr. Cady has contributed several important papers on the subject of piezo-electricity to the PROCEEDINGS of the I. R. E. Since the organization of the Connecticut Valley Section of the Institute he has been its chairman. Dr. Cady was appointed by the Board as Manager of the Institute for 1928. He is a Fellow in the Institute.

CONTRIBUTORS TO THIS ISSUE

Carson, John R.: Received the B. S. degree from Princeton University 1907; E. E. degree 1909, and M. S. degree 1912. Instructor in physics and electrical engineering, Princeton University, 1912–1914. Engineering Department, American Telephone and Telegraph Company 1914–1917. Engineer, Department of Development and Research, American Telephone and Telegraph Company, 1917 to date. In charge of theoretical transmission studies. Awarded Morris Leibmann Memorial Prize by the I. R. E. in 1924 for contribution to engineering circuit theory and for invention of single side-band carrier suppressed transmission system. Author of some forty technical and scientific papers and a treatise on Electric Circuit Theory and operational calculus. Member of the Institute.

Dellinger, J. H.: (See Proceedings for May, 1928).

Hanson, Malcolm P.: Born October 19, 1894. Studied mechanical engineering at University of Wisconsin 1914–17 and engaged in radio experimental and military connection work. During the war served in U. S. Navy in charge of several land stations. In 1918 Commander Ensign and attached to Naval Aviation. After the war returned to University of Wisconsin, 1920–24, continuing studies in electrical engineering and radio, and associated with Physics Department in radio experimental work and as Chief Operator of Stations 9XM and WHA. Since 1924 at Naval Research Laboratory engaged in aircraft radio development work. Was in charge of radio arrangements and special design for Commander Byrd's Antarctic Expedition and Transatlantic Flight and has been detailed Chief Radio Engineer to the Byrd Antarctic Expedition. Associate member of the Institute.

Jolliffe, C. B.: Born in West Virginia, November 13, 1894. Received the B. S. degree from West Virginia University 1915; M. S. degree from West Virginia University 1920; Ph. D. degree Cornell University 1922; from 1917 to 1918 and 1919–20 was instructor in Department of Physics, West Virginia University. Instructor in Physics, Cornell University 1920–22. In Radio Section, Bureau of Standards 1922–26 and 1927 to date.

Marrison, W. A.: Born May 21, 1896 at Inverary, Ontario, Canada. Received the B. Sc. degree from Queens University, Canada, and the M. A. degree from Harvard University. During the war was wireless mechanic in Royal Flying Corps. Received the B. Sc. degree in Physics at Queens University in 1920. Received the M. A. degree in mathematics and physics at Harvard University in 1921. Since 1921 has been in the Western Electric Company and Bell Telephone Laboratories working on development of constant frequency sources, studies of quartz crystals as resonators, temperature control, and picture transmission. Member of the Institute.

O'Neill, H. M.: Born September 15, 1899 at Moneton, New Brunswick, Canada. Actively engaged in radio work since 1920. First as an

operator and later on test and engineering for the General Electric Company. For the past several years has been engaged in antenna design and investigations of antenna characteristics.

Pratt, Haraden: (See PROCEEDINGS for May, 1928).

Zandonini, Elizabeth M.: Born December 11, 1898 in New York City. Graduate of McKinley Manual Training High School, Washington, D. C. 1918 and National Radio Institute 1918. Instructor of radio in Reconstruction Division of War Department, 1919–20. Owner and operator of amateur radio station 3CDQ, 1921 to date. In radio section, Bureau of Standards, 1921 to date.

INSTITUTE ACTIVITIES

Professor Zenneck Coming to the United States

Word has just been received by the Institute that Professor Jonathan Zenneck of the Technical High School, Munich, Germany, will attend the September 5th meeting of the Institute in New York City to receive the Institute Medal of Honor and to deliver a paper.

Special arrangements are being made for this meeting. Complete details will be announced in the next issue of the PROCEEDINGS.

June Meeting of the Board of Direction

At the June meeting of the Board of Direction, held in the office of the Institute on June 6th, the following were present: Arthur Batcheller, Ralph Bown, W. G. Cady, J. H. Dellinger, A. H. Grebe, R. A. Heising, Donald McNicol, and J. M. Clayton.

The following were transferred or elected to the higher grades of membership: Transferred to the grade of Fellow, Stuart Ballantine and Lewis M. Hull. Transferred to the grade of Member: I. J. Adams, Edward L. Bowles, J. E. Brown, Glenn Browning, John C. Burchard, C. W. DeRemer, John DiBlasi, Frank B. Falknor, James L. Finch, Harry W. Houck, James C. McNary, Earle M. Terry, and Harold A. Wheeler. Elected to the grade of Member: A. M. Cheftel, W. C. Evans, W. A. Marrison, J. C. Randall.

One hundred and sixteen Associate members and twenty Junior members were elected.

J. H. Dellinger was appointed to the Advisory Committee of the United Engineering Society to co-operate in the policy of this organization in enlarging the scope of its Engineering Index.

Committee on Institute Awards

A standing committee to consider candidates for the two annual Institute awards, the Morris Leibmann Memorial Prize and the Institute Medal of Honor, was authorized by the Board of Direction at its last meeting. A committee composed of the following members of the Institute has been appointed: J. V. L. Hogan, (Chairman), L. W. Austin, Ralph Bown, W. G. Cady, and A. Hoyt Taylor.

This committee will make recommendations to the Board of Direction for the 1928 Morris Leibmann Memorial Prize.

Members of the Institute having any candidates in mind should communicate with any member of this committee before September 1st.

Preliminary 1928 Standardization Reports

The preliminary draft of report of the Institute's Committee on Standardization for 1928, as submitted by the seven subcommittees, is now available in printed form.

This preliminary report has been prepared for submission to the main Committee on Standardization for final action. It is a document of some one hundred pages.

Members of the Institute who are interested in standardization should receive a copy of this preliminary draft. Copies will be mailed free of charge upon application to the Institute office; however, only a limited supply is available. The comments and criticisms of all members are cordially solicited.

Foreign High-Frequency Assignment

The attention of the Institute membership is called to the Radio Service Bulletin, No. 133, dated April 30th, 1928, in which will be found a compilation of high-frequency assignments in foreign countries in which is shown the location of stations, call letters, and remarks as to type of service. A copy of this bulletin may be obtained from the Superintendent of Documents, Government Printing Office, Washington, D. C. for five cents.

Change of Policy in Handling Applications for Membership

At the meeting of the Board of Direction held on June 6th, the following change in the policy of handling applications for transfer or election to *any* grade of membership in the Institute was adopted. The Committee on Admissions will examine, monthly, all applications for transfer or election to any grade of membership. The names of those applicants whose applications have been approved will then be published in the next issue of the Proceedings, which will be in the mail in sufficient time to allow all members of the Institute to advise the office of the Secretary if there are any objections to the transfer or election of any of the applicants listed.

At the meeting of the Board of Direction following the

publication of the PROCEEDINGS, these applicants will be considered by the Board of Direction and appropriate action taken.

This new routine will materially increase the time required by the Board of Direction acting upon an application, the normal time, it is expected, being approximately two months from the date of receipt of application by the Institute.

The August issue of the PROCEEDINGS will contain the first list of such applications.

Institute Meetings

New York Meeting

At the meeting of the Institute held in New York City on June 6th, in the Auditorium of the Engineering Societies Building, 33 West 39th Street, the following papers were presented: "Aircraft Radio Equipment," by Malcolm P. Hanson of the U. S. Naval Research Laboratory; "Radio Aids to Air Navigation," by J. H. Dellinger and Haraden Pratt, presented by Mr. Pratt; a two-reel motion picture illustrating some of the developments carried on by the Army in directive radio transmission and reception, shown through the courtesy of Captain William H. Murphy of the Signal Corps Radio Laboratories, Ft. Monmouth, New Jersey.

The two papers are printed elsewhere in this issue. A limited supply of copies in pamphlet form are available to members of the Institute and can be obtained upon application to the Secretary.

Following the presentation of the papers and the motion picture film, the following took part in the discussions: Ralph Bown, Stuart Ballantine, William H. Murphy, J. H. Dellinger, M. P. Hanson, and others.

Over five hundred members of the Institute and guests attended this meeting.

Atlanta Section

A meeting of the Atlanta Section was held on May 9th in the Ansley Hotel, Atlanta, Ga. D. C. Alexander, vice-chairman of the Section, presided. F. H. Schnell, of the Burgess Battery Company at Madison, Wisconsin, presented a paper "Experimental High-Frequency Radio for Aircraft." In the paper two transmitters were described, one for ground and the other for aircraft. A very compact aircraft receiver for high-frequency work

was also described in detail. The speaker described the many experiments conducted by the Burgess Battery Company in the development of this equipment. One model of the aircraft transmitter and receiver is said to weigh only fifty-three pounds including the power supply.

C. F. Daugherty, engineer in charge of Station WSB, arranged to broadcast this meeting through WSB. The talk by Mr. Schnell was also broadcast over portable Station 4 PAG on 85 meters, special permission having been obtained from the Federal Radio Commission.

Seventy-five members and guests attended this meeting of the Section.

Following the paper, the announcement of the election of 1928 officers of the Atlanta Section was made as follows: Walter Van Nostrand, chairman; D. C. Alexander, vice-chairman; and George Llewellyn, secretary.

The next meeting of the Atlanta Section will be held on September 13th at which time Irving Wolff of the Radio Corporation of America will deliver a paper "Sound Measurements and Loudspeaker Characteristics."

Buffalo-Niagara Section

On May 9th a meeting of the Buffalo-Niagara Section was held in Foster Hall, University of Buffalo. L. C. F. Horle presided. Dr. L. G. Hector, of the University of Buffalo, presented a paper "Measuring Instruments." Professor Hector outlined a philosophy of measuring and applied this to the case of electrical measuring instruments. All different types of movements and their uses were taken up by Professor Hector, and manufactured examples were exhibited. Professor Hector illustrated with laboratory apparatus the various principles involved in the different types of movements. He also pointed out the differences and likenesses between various types of meters.

Thirty-five members were present at this meeting.

On June 13th a meeting of the Buffalo-Niagara Section was held in Reickerts' Tea Room, 190 Delaware Avenue, Buffalo. L. C. F. Horle and I. R. Lounsberry presided.

This meeting was the annual meeting of the Section and was preceded by a dinner. W. K. Powell presented a talk on "Traffic."

The election of officers of the Buffalo-Niagara Section for the coming season took place. L. C. F. Horle was elected chair-

man; L. G. Hector, vice-chairman; and C. J. Porter, secretary-treasurer. The reports of the various committees of the Section were read and approved by the members present.

Thirty-eight members of the Section attended this meeting.

Connecticut Valley Section

In Scott Laboratory, Middletown, Connecticut, a meeting of the Connecticut Valley Section was held on June 1st. K. S. Van Dyke, vice-chairman of the Section, presided. He presented a paper, "Some Recent Experiments with Quartz Spheres," in which he described a number of very interesting phenomena which take place when quartz spheres are made to resound at their natural or harmonic frequencies. The experiments were illustrated with lantern slides and motion pictures. Following the talk, the meeting adjourned to one of the rooms of the laboratory in which Dr. Van Dyke gave demonstrations.

Los Angeles Section

On May 21st a meeting of the Los Angeles Section was held in the Elite Cafe, 633 S. Flower Street, Los Angeles. D. C. Wallace, chairman of the Section, presided. Two papers were presented. The first by J. J. Jackosky on "Geophysical Prospecting." The second paper, by A. A. Barber on "Electrical Measurements", was illustrated by means of a motion picture film loaned by the Weston Electrical Instrument Corp. Seventy members of the Section attended this meeting.

The next meeting of the Section will be held in the Elite Cafe, September 17th.

Philadelphia Section

A meeting of the Philadelphia Section was held in the Franklin Institute on June 1st. J. C. Van Horn, chairman of the Section, presided. Edgar H. Felix presented an illustrated paper on the "Rayfoto System of Picture Broadcasting."

A general discussion followed the presentation of the paper. One hundred and forty members and guests attended this meeting. The next meeting of the Section will be held on June 22nd in the Franklin Institute.

Pittsburgh Section

In the Assembly Room of the Fort Pitt Hotel, Pittsburgh, a meeting of the Pittsburgh Section was held on May 11th.

W. K. Thomas, chairman, presided. Dr. Phillips Thomas, of the Westinghouse Electric and Manufacturing Company, presented a paper, "Two Meter Tube." The paper described a two-meter oscillator connected in the Hartley circuit. Location of the nodes was illustrated through the use of neon-argon indicators, and their resonant indicators employing flashlight bulbs. The possibilities of the construction of two-meter tubes for the generation of 50 to 100 kilowatts of power were discussed. A speculative analysis of the generation of 50 to 100 kilowatts of power at 10 to 20 centimeters and the use of reflectors for such wavelengths were given.

Thirty-seven members attended this meeting.

The next meeting of the Pittsburgh Section will be held on September 18th in the Fort Pitt Hotel.

Seattle Section

On April 28th a meeting of the Seattle Section was held in the Telephone Building of Seattle. W. A. Kleist, chairman of the Section, presided. A paper by W. V. Sylvester and H. E. Renfro on "Communication Systems of the City Light Department" was presented. Mr. Sylvester gave a talk on the requirements of a communication system for use in conjunction with a power supply plant, pointing out that reliability was highly important in connection with load despatching and other business. The necessity for communication with generating plants located in isolated places was also mentioned. Problems in the design and maintenance of such a system were covered, with a summary of the troubles encountered, such as noise from induced voltages to ground, hazards to life in time of power-line failure, etc. Methods of protection both to the plant and the personnel were described in detail.

Mr. Renfro described the radio telephone system used between Seattle and the hydro-electric plant on the Skagit River, one hundred and twenty miles distant. He also discussed the possibility that transmission was taking place partly over the power line and partly through space since the antennas at both ends are located near the power line. The problem of signalling over this system, it was pointed out, has to be further improved before it can be called entirely satisfactory.

Washington Section

A meeting of the Washington Section was held in Picardi's Cafe, 1417 New York Avenue, N. W., Washington, D. C. on May 10th. Forty-three members attended the dinner preceding the meeting. F. P. Guthrie, chairman of the Section, presided.

A paper by Malcolm P. Hanson on "Aircraft Radio Installations" was presented by Mr. Hanson, and another paper by J. H. Dellinger and Haraden Pratt, of the Bureau of Standards, on "Radio Aids to Air Navigation" followed. In the discussion which followed, C. P. Mirick, A. H. Taylor, and others took part.

Sixty-eight members and guests attended the meeting.

Both papers are printed elsewhere in this issue.

Committee Work

1929 Convention Committee

A Preliminary Committee on the 1929 Convention was appointed by the Board of Direction and the Washington Section of the Institute with membership as follows: J. H. Dellinger, Chairman, Ralph Bown, J. M. Clayton, A. Hoyt Taylor, Guy Hill, S. S. Kirby, F. P. Guthrie, C. B. Jolliffe, and Alfred Crossley.

A meeting of this Preliminary Committee was held in Washington on May 22nd. Tentative plans for the 1929 Convention were drawn up with appropriate recommendations to the Board of Direction.

The Board of Direction of the Institute approved the report of this Preliminary Committee and authorized the appointment of the following chairmen of the various committees: Executive Committee, F. P. Guthrie; Registration and Arrangements, Alfred Crossley; Fellowship, Professor E. C. Kennely; Trips, S. S. Kirby; Banquet, F. P. Guthrie; Publicity, R. D. Heinl.

A Preliminary Committee to consider entertainment of ladies present was appointed as follows: Miss E. M. Zandonini, Miss Mary T. Loomis, Mrs. F. P. Guthrie, and Mrs. J. H. Dellinger.

Committee on Admissions

A meeting of the Committee on Admissions was held at 1:30 P.M. on June 6th in the office of the Institute. The following members were present: R. A. Heising, Chairman; H. F. Dart, and E. R. Shute. The Committee considered cases of thirty-five

applicants for transfer or election to the higher grades of membership in the Institute.

Committee on Membership

A meeting of the Committee on Membership was held in the Fraternities Club Grill, 38th Street and Madison Avenue on July 6th. The following members of the Committee were present: H. F. Dart, Chairman, I. S. Coggeshall, and H. B. Coxhead. A number of problems involved in the increase of membership in the Institute were discussed.

Committee on Sections

A meeting of the Committee on Sections was held on May 18th in the Institute Headquarters. The following were present: Donald McNicol, Chairman; E. I. Green, M. Berger, and E. I. Shute. The Committee approved the petition of members residing within the territory of New Orleans, La. for the chartering of a New Orleans Section.

Correspondence looking to the formation of Sections in St. Louis and Cincinnati is being undertaken by the Committee.

Mr. Shute gave a report of his trip to the Pacific Coast where he visited the Seattle and San Francisco Section officers.

CHARACTERISTICS OF CERTAIN BROADCASTING ANTENNAS AT THE SOUTH SCHENECTADY DEVELOPMENT STATION*

BY

H. M. O'NEILL

(Radio Engineering Department, General Electric Company, Schenectady, New York.)

Summary—*In this paper, the characteristics of broadcast antennas of various standard forms are discussed and experimental data presented on actual installations at the South Schenectady Developmental Station. The effect on signal strength, as measured locally, of varying the antenna height is considered; and also the effect of high steel towers on antennas operated at 380 meters wavelength. Antenna ground system losses, local radiation losses, antenna directional effects and field distortion are also discussed to a limited extent.*

THE presentation of a few experimental results with the modifications of theory suggested thereby may be helpful in obtaining a clearer view of the complex action of broadcast antennas. The following paper is a summary of such results and is based on several investigations conducted principally at the South Schenectady Developmental Radio Station of the General Electric Company. It frequently happened during these investigations that what was meant for the treatment of general problems turned out to be the examination of special cases. This, however, is due to the extreme sensitiveness of radiating systems to external influences; and, as such influences are active to some extent in the average installation, it may be that the most practicable way of arriving at a satisfactory basis for antenna design is through the accumulation of data such as are presented in this paper.

Special terms are used to denote the quantities having to do with antenna characteristics. Principal among these terms are: radiation efficiency, total effective resistance, antenna effective current, radiation resistance, antenna effective height, meter amperes, and radio field intensity. All of these terms are defined in the I. R. E. Report of the Committee on Standardization for 1926, to which reference should be made if necessary for clearer understanding of what follows.

Radiation efficiency is generally accepted as being the prime requisite of a broadcast antenna; but, in a wider sense, the most desirable broadcast radiator is that which most consistently

* Original Manuscript Received by the Institute, May 8, 1928.

serves the greatest number of receiving stations. We therefore desire not only that the antenna be an efficient radiator but that the energy radiated be directed so that it ultimately becomes available at distant receivers, and also that it traverse the intervening distance with the least possible attenuation. For this reason, while much of the following discussion concerns radiation efficiency, propagation problems (with the exception of fading) are also considered, since they are definitely associated with the problem of obtaining a truly effective broadcast antenna.

Radiation efficiency is defined as: "The ratio of the power radiated to the total power delivered to the antenna at a given frequency." Total effective resistance and antenna effective current are directly measurable by standard methods and completely determine the total power delivered; but what means have we of measuring the power radiated? From the definitions of the quantities, radiation efficiency may be expressed by the ratio of radiation resistance to total effective resistance; but, unfortunately, radiation resistance is hardly a measurable quantity because it cannot be varied to any extent in a broadcast antenna without at the same time varying the loss resistance in an unknown manner. Three other possible avenues of approach to the problem of radiation efficiency still remain; radio field intensity, antenna effective height, and meter amperes.

The intensity of the radiation field at a distant point can, in general, be increased only by increasing either the amount or concentration of the power radiated; and it is not a function of antenna height whether "effective" or actual, except in so far as the antenna height governs the ratio of radiation to total resistance or alters the distribution of the field. Radiation resistance is no more difficult to estimate or to calculate than effective height; and since it is much more useful in predicting results on a power basis—the logical one—it will be used in the following discussion to the exclusion of roundabout reasoning involving effective height. Meter amperes also are of little value in arriving at broadcast antenna efficiency, because for the determination we must calculate or guess the two components of total effective resistance; and this done, with the efficiency established, what need have we of meter amperes?

It can be easily demonstrated experimentally that field intensity measured at a distance of several wavelengths from the antenna varies directly as the antenna current and consequently as the

square root of the power, both total and radiated. Therefore, if the average is taken of a number of squared values of field intensity measured on a circle of suitable radius with the antenna as center, then this average should be directly proportional to the power radiated through a zone close to the earth's surface. By measurements of this kind made at a constant radius and referred to a common power basis, we can compare the radiation efficiencies of various broadcast antennas. This is subject to the limitation that we cannot be certain, in comparing antennas of different forms, to what extent an increased average intensity, for a given power input, is due to a greater concentration of power close to the horizon rather than to increased radiation efficiency. The measure of radiated power obtained in this manner will, in the following discussion, be expressed in arbitrary units, since in the author's opinion the present radiation formulas and field-intensity standard are not sufficiently exact to justify our attempting to express the result in watts. A description of the instrument used and details of the method of local field intensity measurement are to be found in a paper entitled "Main Considerations in Antenna Design," by N. Lindenblad and W. W. Brown.[1]

The method of radiation measurement outlined in the previous paragraph requires some standard for efficiency comparison. The regular WGY antenna, erected over one of the buildings in the Schenectady Works of the General Electric Company, was adopted as such a standard for the antennas constructed at South Schenectady. This antenna consists of a horizontal flat top 200 ft. long with a tuned downlead at each end, suspended from two 165-ft. self-supporting steel towers, with a height of flat top above the counterpoise of approximately 120 ft. This antenna is of the multiple-tuned type, but due to the comparatively high ratio of antenna height to operating wavelength the full advantage of multiple tuning is not realized in this particular installation. The antenna dimensions and fundamental wavelength (359 meters), indicate that this structure consists essentially of two inverted "L" antennas placed end to end. Since the ground resistance of each antenna is due to the expansion and contraction of its own induced field, it does not appear that the two existing ground paths are in multiple to any greater extent than it is possible for the electric field of one antenna element in collapsing

[1] Presented before New York meeting of the Institute, March 3, 1926. PROC. I. R. E., 14, 3, p. 291; June, 1926.

to make its return path to the system by way of the other element—a process difficult to visualize. It is true that the antennas themselves are in parallel, but this would increase efficiency only if the modification of the field of one due to the presence of the other increased the ratio of radiation to total resistance or if antenna efficiency varied with load. The radiation of this antenna measured at 5 km radius and 380 meters wavelength by the method previously discussed was 290 units.

The South Schenectady Developmental Station is equipped with a number of self-supporting steel towers used in construct-

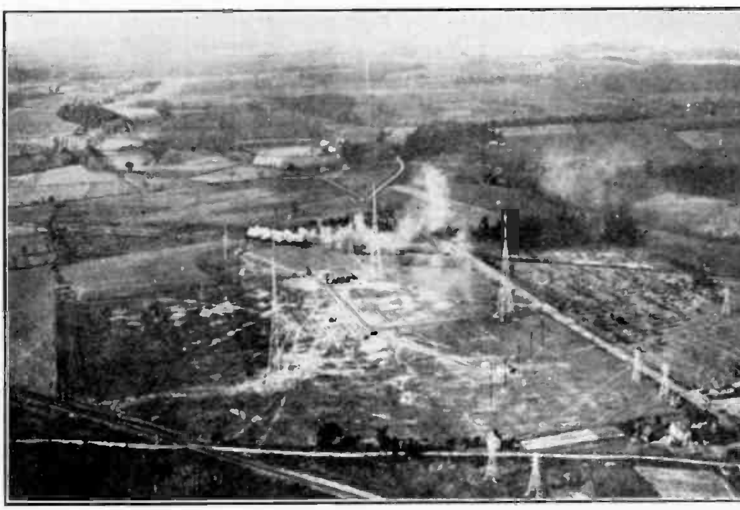
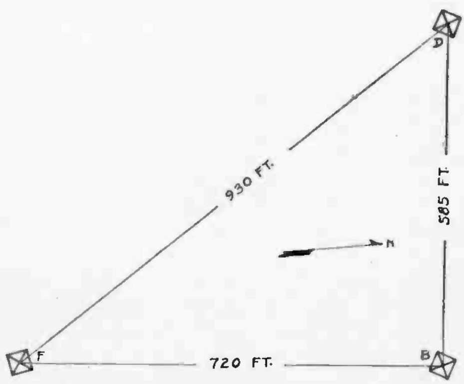


Fig. 1—Airplane View of South Schenectady Radio Station.

ing a variety of antennas required with developmental transmitters operating over a wide range of wavelengths. Among these towers are three having a height of 300 ft., arranged as shown in Fig. 1, and also by the diagram of Fig. 2, on which are given letter designations frequently used for reference in the following discussion.

The first two broadcast antennas at South Schenectady were erected in the vicinity of tower *D*. One of these, a multiple-tuned antenna generally similar to that of WGY, was located to the west of tower *D* and supported at the far end by a 150-ft. steel tower; the second, a vertical antenna 210 ft. long, caged for the upper 120 ft. of its length, was suspended from a triatic at-

tached to tower *D* and was located over the main building, about 100 ft. to the south of the tower. The efficiencies of both these antennas were remarkably low as compared to WGY, and in addition to this, the field intensity patterns indicated an unusual amount of distortion. From the comparison given by Fig. 3, it will be observed that the field patterns have the same general form and that the distortion in each case bears the same relation to the direction of the line joining the antenna and tower *D*, thus indicating that the tower was resonant at or near the operating frequency and was, therefore, responsible for this distortion and possibly also for the low radiation efficiency.



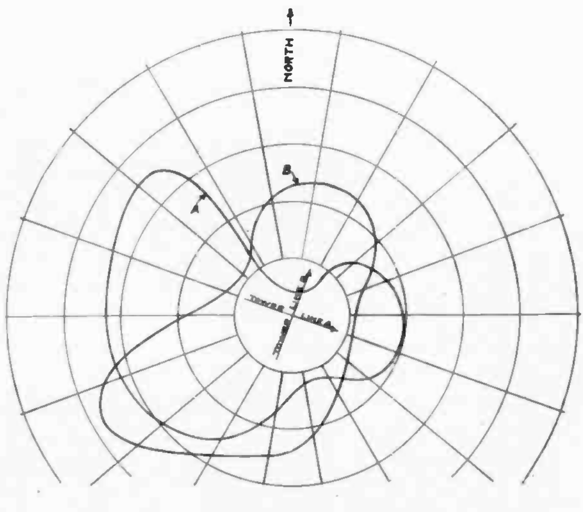
ARRANGEMENT OF 300 FT. TOWERS
SOUTH SCHENECTADY RADIO DEVELOPMENTAL STATION

Fig. 2.

The fundamental wavelength of the vertical antenna was 334 meters, and the resistance at 380 meters 11 ohms. The radiation was 31 units which was extremely low when compared with the 290 units of WGY. As tower *D* was apparently causing trouble a new vertical of the same dimensions as the first was installed with an improved wire ground in the center of span *D-F*, in which position it was nearly equi-distant from all three of the high towers. This antenna had a fundamental wavelength of 360 meters, a resistance at 380 meters of 34 ohms and a radiation at 5 km of 180 units: which was a decided improvement over the first vertical but still far below the 290 units of WGY.

The height of the vertical in span *D-F* was raised to 235 ft. in accordance with the assumption that higher efficiency would accompany increased radiation resistance. This change resulted in

a fundamental wavelength of 378 meters, a resistance at 380 meters of 41 ohms and a radiation of 200 units. The improvement over the lower height was therefore small; and later developments indicated that even this slight increase in efficiency was not due to increased height, but to an accidental shift in the wavelength of tower *B*. The mechanical limit of safe antenna height for this span having been nearly reached, greater radiation resistance could best be obtained by adding a horizontal section to the existing vertical. The 235-ft. vertical was therefore converted into a "T" antenna by the addition of a horizontal 2-ft.



EFFECT OF TOWER D ON FIELD PATTERNS
PATTERN A- TWO POINT TUNED ANTENNA WEST OF TOWER
PATTERN B- VERTICAL ANTENNA SOUTH OF TOWER

Fig. 3.

diameter cage 160 ft. long. The antenna now had a fundamental wavelength of 533 meters and a resistance at 380 meters (measured as usual at the base of the antenna) of 82 ohms. The radiation from this antenna was 210 units, which checks within the error of measurement the value obtained without the horizontal section. Apparently, the problem of inefficiency in this specific case could not be solved through the use of higher radiation resistance; and, as the principal antenna loss appeared to be due to tower resonance, the obvious thing to do was to alter the resonant wavelengths of the towers.

Two practicable means whereby resonant steel towers may be detuned are: the use of insulators in the base of each tower leg; and the simple expedient of attaching wires at the tower top to produce the equivalent of an umbrella antenna. Base insulators lower the resonant wavelength in a manner similar to the action of a series condenser in an antenna circuit; while on the other hand, the effect of the umbrella of wires attached to the tower top is to increase the resonant wavelength. The value of either device will depend on the previously existing relation between tower and antenna wavelengths. Both of these methods were used in trying to increase the efficiency of the "T" antenna in span *D-F*. The base of tower *D* was insulated with special porcelain insulators; and the effects of towers *B* and *F* were limited by detuning wires applied to their tops. By these adjustments

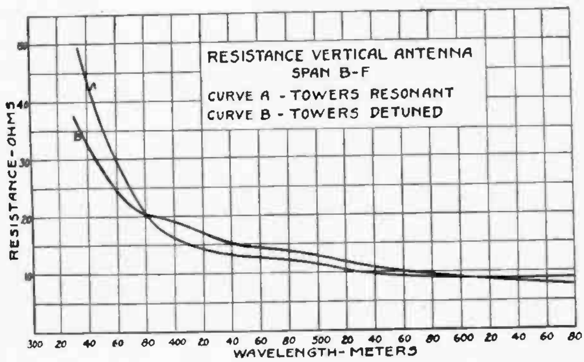


Fig. 4.

to the towers, the antenna resistance at 380 meters was reduced to 63 ohms and the radiation increased from 210 to 280 units.

Until this time the best that could be done with a 235-ft. antenna using 300-ft. towers was to make its efficiency nearly equal to that of a 120-ft. antenna suspended between 165-ft. towers. It subsequently became necessary to erect in span *B-D* an antenna for high power broadcasting. The antenna erected was a vertical 240 ft. long, very similar to that used in span *D-F*, equipped with a 240-ft. diameter radial wire counterpoise, and having a fundamental wavelength of 374 meters. While the resistance of this new vertical at 380 meters was only 23 ohms as compared with 41 ohms for the vertical in span *D-F*, the field intensity per ampere of antenna current was almost exactly the same in each

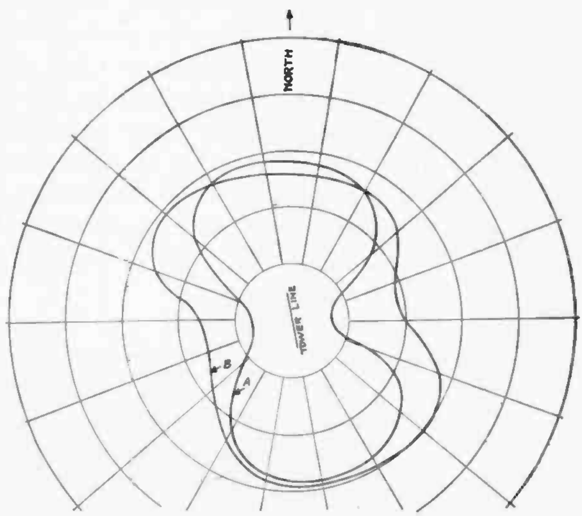
case. This indicates that the radiation resistance was the same for both, and that the reduced resistance in span *B-D* was entirely due to decreased loss. In consequence of this reduced loss the radiation was increased to 370 units.

The above results were obtained, of course, with the tower wavelengths adjusted; but even with this improvement in antenna efficiency, tower effect still existed, as was apparent by a slight elongation of the field pattern along the tower line. The effect of returning the towers to their original condition of resonance was to distort the field pattern into a pronounced figure 8 along the tower line, and to cut the radiation in half. Nevertheless, the measured resistance at 380 meters was still 23 ohms, although it fluctuated widely while the tower wavelengths were being changed. Apparently, the changes in radiation and loss components compensated for one another so as to leave the total resistance unaffected at this specific wavelength; and at the same time reduced the ratio of radiation to total resistance to one half its former value.

The peculiar condition just considered was to some extent paralleled in a simple vertical antenna erected at the center of span *B-F*. Antenna resistance curves made with and without detuning wires on the supporting towers are shown by Fig. 4, from which it will be seen that, while generally different, the curves cross at 380 meters. Field patterns for the two conditions of tower adjustment are shown by Fig. 5: on which curve *A* is the pattern with the towers resonant and curve *B* the pattern with towers detuned. The difference in apparent efficiency should be directly proportional to the difference in pattern area because both patterns were made with the same antenna power, current, and adjustments. Only two 300-ft. wires attached to the top of each tower and extending downward at an angle of 45 deg. were used in producing this pattern difference, but additional wires brought about no further improvement.

The most important loss in broadcast antenna unaffected by neighboring metal structures takes place in the ground path of the currents caused by the rising and falling electric field. The time-distance idea involved in the explanation of electro-magnetic radiation suggests that an increase in the radiation field for a given antenna current is a consequence of the extension of the field to a greater average distance from the antenna, therefore probably—though not necessarily—increasing the average length

of ground path and consequently increasing the ground resistance. Since efficiency depends on the ratio of radiation to total resistance, if the radiation resistance is numerically large, a small numerical increase in loss resistance with increasing antenna height would suffice to hold the efficiency constant. Considerations of this nature led to an investigation at the Developmental Station of the variation in radiation efficiency with antenna height.



FIELD PATTERNS OF VERTICAL ANTENNA IN SPAN B-F
PATTERN A- WITH TOWERS RESONANT
PATTERN B- WITH TOWERS DETUNED

Fig. 5.

The antennas investigated were simple vertical and "T" cage antennas of heights varying from 80 to 240 ft. erected in span *B-F* with the towers detuned. The horizontal cage sections were 2 ft. in diameter and 80, 160 and 240 ft. in length. All antennas used the same counterpoise which was 240 ft. in diameter, consisting of 28 radial wires. Radiation measurements were made on all antennas by the method described early in this paper. The radius of measurements was one mile, the wavelength 380 meters, and the antenna power input 200 watts for all measurements. The arbitrary basis for field intensity values was not the same as for previous measurements; hence there can be no direct

comparisons of efficiencies between this group of antennas and those previously measured.

The results of the measurements on the simple vertical and the 160 ft. "T" antenna are shown by Fig. 6. It will be seen that the curve for the 160-ft. cage is practically a horizontal line, while that for the vertical indicates a rapid increase in efficiency with height until a height of 200 ft. is reached. Beyond this point, the curve flattens out although the antenna fundamental was still below 380 meters. The range of fundamental wavelengths for the simple vertical was 135 to 310 meters and that for the 160-ft. flat top 320 to 535. The two curves shown might therefore be plotted in a single continuous curve of efficiency against fundamental wavelength; and this latter curve would be

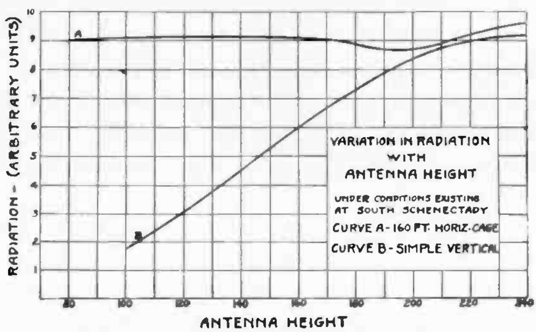


Fig. 6.

similar to what we might predict would be obtained by progressive increases in the height of the vertical up to 410 ft. The curves for the 80 and 240-ft. horizontal lengths, though somewhat more irregular than for the 160-ft. length, indicated little variation in efficiency with height but showed a slight maximum in the vicinity of 150 ft.

It is very important to bear in mind that curves such as those of Fig. 6 must not be taken as a general indication of what may be expected in the average case. Unless measurements of this kind are checked by similar data taken under different conditions of soil resistance, tower effect, etc., general conclusions drawn therefrom are unjustified.

An 80-ft. antenna with a 160-ft. horizontal length, under the conditions existing at South Schenectady, had shown as high a radiation efficiency locally as a 240-ft. vertical antenna; but would this condition also hold great distances? As a preliminary step in

determining this point distant comparisons were made on a flat-top antenna only 50 ft. high and the efficient 240 vertical in span *B-D*. The flat top was 80 ft. in diameter with a central downlead extending to a 200-ft. diameter radial wire counterpoise. The fundamental wavelength was 288 meters and the resistance at 380 meters 5 ohms; of which at least 1 ohm is known to have been due to losses in the temporary tuning equipment used. Measurements were made with a graphic recording instrument on both day and night transmissions at 50, 120, and 170 miles. The results of these measurements indicate no marked difference in signal strength either at 50 or 120 miles; but at 170 miles the vertical was distinctly superior on both day and night transmissions. However, additional data supplied by independent observers indicate that propagation conditions, at the time of the 170-mile measurements, may have favored the vertical. Nevertheless, there is no question but that a difference was measured. It therefore appears either that the vertical was superior at 170 miles or that propagation conditions influence radiation from a high vertical in a different manner than the radiation from a low flat-top.

The use of different antenna forms may result in changes of energy concentration from the horizon to the zenith. If such changes occur they will alter the apparent antenna efficiencies based on the local field measurements. There is a possibility that such an effect may have been partially responsible for the shape of the curves of Fig. 6. The following discussion on this point is an extension of conclusions arrived at mathematically by various investigators.

From the voltage and current distribution along an ideal quarter-wave antenna it will be seen that the greatest electric charge is on the upper part while the magnetic field is most intense near the lower end. Considering the electro-magnetic field surrounding an element of antenna length near the base, all of the electric lines of force from the antenna will pass through the zone in a vertical direction; and the magnetic lines will be at a maximum and in horizontal planes. Bearing in mind that the direction of wave propagation is at right angles to both the electric and magnetic fields; and that the energy acting is proportional to the vector product of the intensities of the two fields: it will be apparent that the radiation due to this zone will have a maximum intensity and will be propagated in a horizontal direc-

tion. Taking zones surrounding successive elements of length higher and higher upon the antenna, the magnetic field becomes less and less and the average direction of the electric lines approaches more nearly the horizontal. Consequently, with increasing height the contribution to the total radiation of the zones surrounding the antenna elements becomes less and less and the direction of propagation approaches the zenith.

With a fixed operating wavelength, a decrease in antenna height from a quarter wavelength requires that a loading coil be used at the base; and, considering the voltage and current distributions on the shortened antenna, it appears that this is equivalent to winding the lower portion of a quarter-wave antenna—which contributes most to low-angle radiation—into a non-radiating coil. The part of the antenna contributing mostly to high-angle radiation still remains; and this may cause an upward tilt of the radiated wave, thus producing an apparent decrease in antenna efficiency when based on local field measurements

In the mathematical analysis of antenna characteristics given in "Electrical Oscillations and Electric Waves," by G. W. Pierce, it is assumed that a flat-top antenna consists substantially of a quarter-wave antenna with the upper part bent over in such a way that the voltage and current distributions remain unaltered. This, however, would represent only one limiting form of flat-top. The other limit would be reached if the dimensions of the flat top were expanded symmetrically about the vertical length so as to retain the same fundamental wavelength that existed with the quarter-wave antenna. The flat-top might then be assumed to be equivalent to replacing the upper part of the antenna by a circular conducting plate, in such a way as to retain the same field distribution about the remaining vertical length, as existed with the quarter-wave antenna. On this assumption, the only remaining part of the quarter-wave antenna is that which contributes mostly to horizontal radiation; and the use of such an antenna should result in concentration of energy close to the horizon. The characteristics of the "T" antenna used in securing the curve of Fig. 6 may have approximated those of the second limit closely enough to produce the effect of no apparent decrease in radiation efficiency with decreasing antenna height.

When antennas of low height are used, the losses in the ground system become an important factor in radiation efficiency. The question therefore arises as to the merits of an elevated conter-

poise as compared with a buried wire ground. It is possible that, at broadcast wavelengths, the action of buried wires in providing a low-resistance path for the induced electric field is not very pronounced. The impedance of the wires themselves will be high due to their reactance at these frequencies while the impedance of the capacitive leakage path between wires will be low. A flow of current along the wires must be accompanied by a voltage drop and, as the potential of the uninsulated wires remains practically the same as that of the surrounding soil, it appears that the effectiveness of the wires is decidedly limited. On the other hand, an insulated counterpoise can assume a high potential which being opposite in sign to the potential of the antenna, facilitates the action of the counterpoise as a collector of lines of force. If the counterpoise is of sufficient height and dimensions,

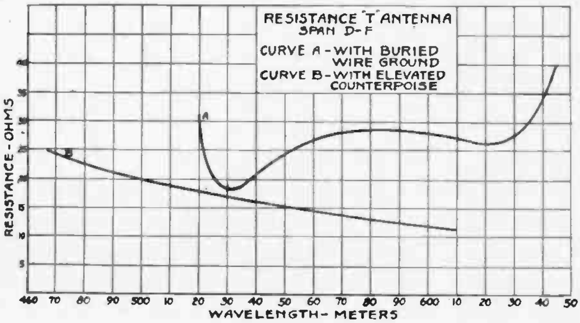


Fig. 7.

no appreciable earth currents should be present near the antenna; and due to the multiplicity of wires, the resistance of the counterpoise should be lower than that of the antenna conductor itself. Nevertheless, a counterpoise has obvious mechanical disadvantages as compared to a buried wire ground, so that its use should be conclusively justified by increased antenna efficiency. Such data as have been accumulated at the Developmental Station indicate that an insulated counterpoise does not increase the efficiency of a very high broadcast antenna by more than a small percentage. There is no question but that lower antenna resistance results from the use of a suitable counterpoise; but apparently a part of this is due to a reduction in radiation resistance. An example of extreme variations which may occur is shown by Fig. 7, the curves of which were based on data secured on the "T" antenna in span *D-F*. The measurements on the counterpoise

were made immediately after those with the wire ground, with no changes to the antenna itself. Therefore, the irregularities shown by the curve for the buried wire ground are definitely due to the use of this system.

Ground losses, far from being confined to the counterpoise or wire ground, extend to every part of the earth's surface reached by the radiated wave. Assuming the correctness of the ordinary radiation laws, the radiation field varies inversely as the distance from the antenna; and the induced field varies inversely as the square of the distance, being equal to the radiation field at a distance beyond the limits of the average ground system. For this reason, the losses in the induced and radiated fields overlap, thus making a clear division between power lost and power radiated practically impossible. Special precautions to reduce ground losses close to the antenna are advantageous simply because the induced field has comparatively a very high intensity in this region. For high efficiency as measured at distant points it is just as necessary to secure a favorable ground path for the radiated field; and this can be accomplished only by careful selection of the broadcast station site.

An indication of the extent of the ground losses occurring locally in the radiation field of an antenna can be obtained by field intensity measurements. For this purpose the measurements should be made along several radial lines from the antenna, and the decrease in field intensity due to the normal spreading of the waves taken care of by multiplying each measured value by the distance of the measurement point from the antenna. The degree to which an average curve (of these "intensity by distance" values plotted against distance) varies from a horizontal line should be indicative of the decrease in field intensity due to ground absorption.

Measurements of this kind were made on two broadcast stations which were equipped with almost identical antennas and operated at not greatly different wavelengths, but whose locations were very different as far as soil and topography are concerned. The curves obtained from these measurements are shown by Fig. 8, and indicate that station No. 2 would require four times the power input of station No. 1 to produce the same average signal strength at 20 km. Assuming the same average absorption beyond 20 km for both stations, the advantage of the location of station No. 1 will be apparent. The differences

indicated by these curves, while probably extreme, show the importance of securing the best possible antenna location within the permissible limits. Even where the choice of location is decidedly restricted, measurements made with portable equipment prior to final selection of the site may be helpful in avoiding the vicinity of small highly absorbing areas. The power lost in such an area will depend on the percentage of total radiated power acting through the area; and if the area is at a considerable distance from the antenna, it will occupy an arc which is only a small percentage of the radiation circle and consequently cause but little loss.

The effectiveness of increasing the power output of a broadcast station will be reduced by ground absorption of the radiated

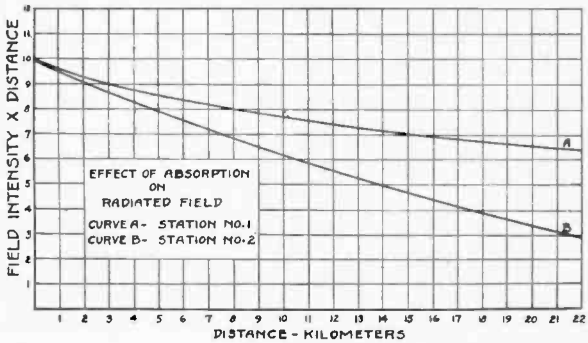
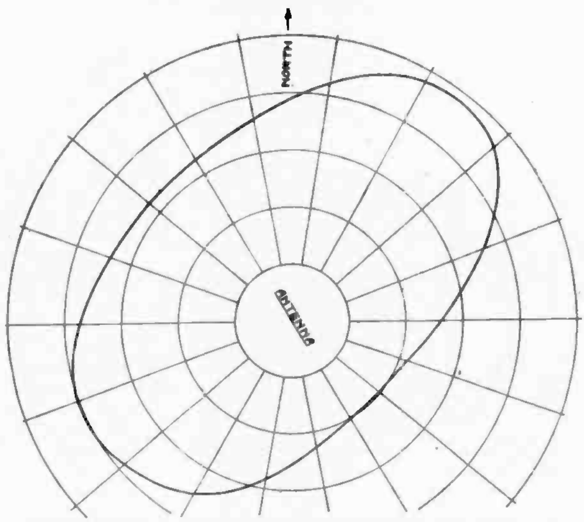


Fig. 8.

field. The object of increased power is greater broadcast range; and for the word "range" to have a meaning we must assume the existence of some minimum signal necessary for normal broadcast reception. With a circular radiation pattern and uniform propagation conditions, the range of the station would be the distance from the antenna to a point where this minimum signal was obtained; and the area served would be proportional to the square of this distance. Two conditions act to reduce the radiated field intensity: the normal spreading of the waves by which doubling the circumference (or radius) of the radiation circle cuts the intensity of the field in half; and absorption, acting according to the inverse compound interest law, by which a certain percentage of the existing field is lost for each unit of distance traveled. Now, increasing the power output of a station to four times its previous value will double the field intensity at the point of first minimum signal level regardless of absorption;

and, if beyond this point there was only the normal expansion and no absorption, the point of minimum signal would be reached at twice the distance and the area served increased in proportion to the power. Absorption, however, will exist beyond the range of the first power and consequently the minimum signal in the second case will fall short of twice the distance and the increase in area will be less than proportional to the power. It may easily be shown graphically that the lower the minimum signal level adopted and the higher the power in the first instance, the less



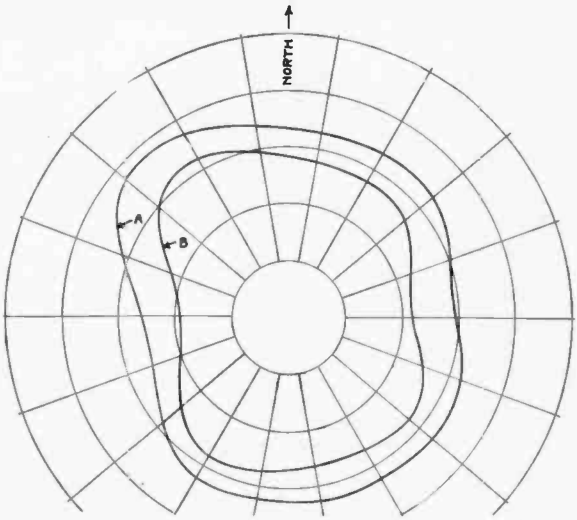
GENERAL FORM OF WGY FIELD PATTERN
AT 5 K.M.

Fig. 9.

marked, on a percentage basis, will be the increase in area served with increased power.

In general the rate of absorption varies in different directions from the broadcast station; and this is also true of the distribution of possible receiving stations within range. In addition, natural barriers to wave propagation may exist beyond which a specific station is ineffective. These factors indicate that directional radiators may have certain applications to broadcasting. It must be borne in mind, however, that directive radiation is equivalent to increasing the power in some directions and decreasing it in others, and consequently will be modified by the

effects of absorption. Therefore, the shape of the calculated or measured field intensity pattern will be different from that of the minimum signal level curve. The field pattern shows variations of intensity at a constant distance from the antenna, while the minimum signal curve shows variations in distance for a constant field intensity; and the percentage of absorption varies with the distance from the antenna and not with field intensity. The result, with uniform propagation, will be that the minimum



FIELD PATTERN COMPARISON VERTICAL & FLAT TOP ANTENNAS

PATTERN A- VERTICAL ANTENNA 240 FT. LG.
PATTERN B- "T" ANTENNA. HORIZONTAL LENGTH 240 FT.
VERTICAL LENGTH 80 FT.

Fig. 10.

signal curve as compared with the field pattern will show the high points reduced and the depressions partly filled out. That is, the minimum signal curve will approach more nearly a circular form than indicated by the field intensity pattern. This effect is probably responsible to a large extent for the apparent "healing" of distorted signal level curves as the distance from the antenna is increased.

As an example of directive radiation accidentally obtained, the general form of field pattern on the regular WGY antenna is shown by Fig. 8. This antenna was previously described as consisting of two inverted "L" antennas placed end to end. The separation distance of the downleads, 200 ft., is approximately

one-sixth of a wavelength; and the space-phase difference brought about by this separation, together with a similar possible time phase relation, is sufficient to account for the elliptical form of the pattern. The usual flat-top lengths of inverted "L" and"T" antennas used for broadcasting are not sufficient to produce direc ive radiation. This is indicated by the almost exact shape of the two field patterns shown by Fig. 9, one of which was made on a vertical antenna 240 ft. long and the other on an 80-ft. "T" antenna with a 240-ft. horizontal section. Such directivity as does exist in these patterns is due to the action of the 300-ft. supporting towers.

The ultimate conclusion from such investigations as those discussed in this paper must be that each broadcast antenna presents a separate engineering problem requiring individual treatment. A great advance in establishing a sound engineering basis for the attack of such problems would be made by comparing the broadcast range of a number of existing stations. Work of this nature has in the past been hindered by the lack of suitable measuring instruments and by the absence of an authoritative field intensity standard. Precision instruments are now available capable of measuring the intensity of the radiated field under full power conditions, from within a few wavelengths of the antenna to the limits of the station range. Calibration methods have also been extensively studied, with the result that measured intensities are considered to be close to the true values in microvolts per meter.

A standard method of instrument calibration giving a fairly close approximation to microvolts per meter is a most urgent requirement. Scientific accuracy is less important at the present time than a general basis for comparison of the broadcast ranges of existing stations. Of course, the distance of minimum signal level is obscured by fading, but we can take the daylight range as a performance basis; and assume, until we learn more about fading and radiation generally, that an antenna which is good in the daytime is also good at night. By considering each station as a separate problem in radiation we should be able to do much towards increasing the effectiveness of the stations. The result would be that we would have less broadcasting, in the literal sense of the word, and more of what the industry seems bound to become, a thoroughly efficient public service.

DEVELOPMENT OF RADIO AIDS TO AIR NAVIGATION*

By

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(Bureau of Standards, Washington, D. C.)

Summary—*The development of aircraft has reached a stage where further progress depends upon the conquest of adverse meteorological conditions. The most promising avenue to such mastery of the elements is through adaptations of radio. Intensive work extending over two years has resulted in the development and practical demonstration of a complete set of radio aids to flying on the civil airways of the United States. This development was carried on by the Bureau of Standards for the Aeronautics Branch of the Department of Commerce.*

The radio aids, which will now be installed on the principal airways, comprise a radio beacon system and telephone service from ground to aircraft. The required radio equipment on the airplanes is reduced to a short pole antenna and a simple receiving set weighing a few pounds, including a visual indicator which tells the pilot whether he is on the course or how far off. All of the expensive and powerful apparatus necessary for the system is on the ground, maintained by the Government.

The radio beacons operate in the frequency band 285 to 315 kc and the telephone stations in the band 315 to 350 kc. These are allocated to air service by the 1927 International Radio Convention. For the present the beacons are adjusted to the frequency of 290 kc and the telephone stations to 333 kc.

The directive radio beacon is a special kind of radio station, usually located at an airport, just off the landing field. Instead of having a single antenna like an ordinary radio station, it has two loop antennas at an angle with each other. Each of these emits a set of waves which is directive, i.e., it is stronger in one direction than others. When an airplane flies along the line exactly equidistant from the two beams of radio waves, it receives signals of equal intensity from the two. If the airplane gets off this line it receives a stronger signal from one than the other.

The indicator connected to the receiving set on the airplane shows when the signals from the two beams are received with equal intensity, by means of two vibrating reeds which are tuned to different modulating frequencies used on the two antennas at the directive radio beacon station. When the beacon signal is received the two reeds vibrate. The tips of these reeds are white in a dark background so that when vibrating they appear as a vertical white line. The reed on the pilot's right is tuned to a frequency of 65 cycles and the one on the left to 85 cycles. It is only necessary for the pilot to watch the two white lines produced by the vibrating reeds. If they are equal in length, he is on his correct course. If the one on his right becomes longer than the other, the airplane has drifted off the course to the right (into the region where there is

* Original Manuscript Received by the Institute, May 8, 1928.
Revised Manuscript Received June 4, 1928.
Presented before Washington Section of the Institute, May 2, 1928.
Presented at New York Institute Meeting, June 6, 1928.
Publication Approved by the Director of the Bureau of Standards of the Department of Commerce, Washington, D. C.

more of the 65 cycles). If he drifts off the course to the left, the white line on the left becomes longer.

Successful flights have been made up to 135 miles, in fog and over hazardous mountain terrain. This distance is more than enough to demonstrate the success of the system, as it is contemplated that the directive radio beacon stations will be placed not over 200 miles apart. Beacons placed at such distances, with a straight airway between them, will be supplemented by small marker beacons at intervals along the route. A characteristic signal from a marker beacon will show on the visual indicator aboard the airplanes what point is being flown over.

The whole receiving system comprises a small indicator unit on the instrument board weighing one pound, a receiving set weighing less than 15 pounds, and a 15-pound battery. The receiving system is very little affected by interference, including engine ignition interference, which has hitherto been the bar to satisfactory use of radio on airplanes.

Introduction

THE urge for dependable instrumentalities of aerial navigation has become progressively more intense: a natural consequence of the development of more reliable aircraft, the successful accomplishment of pioneer long-distance flying, and the commercial operation of scheduled air services. The operation of aircraft is peculiarly subject to uncontrollable meteorological conditions. The very navigational means which such conditions demand have hitherto been lacking.

The period preceding the World War saw aeronautics develop out of the stage of experimentation into the stage of fact and reality. The war provided a field of use which stimulated intensive development in everything aeronautic, creating a foundation of experience upon which this new instrumentality of transportation has since grown. During the war the use of radio as an adjunct to military flying received some attention, and both telegraph and telephone sets were successfully used for moderate distance communication.

In Europe, aeronautic post-war development took the form of subsidized air passenger lines operating on schedule. The problem of maintaining schedules during fog and bad weather very soon required the use of radio as a navigational aid. The form in which radio has evolved, to assist bad-weather flying in Europe, is a two-way radio telephone (or telegraph) communication service between ground and aircraft, supplemented by a system of position finding by means of direction-finder stations on the ground. Upon radio request from an aircraft, two or more ground direction-finder stations locate the aircraft by triangula-

tion and send the information back. The operation is similar to that of the radio compass service rendered by our Navy Department to merchant ships entering American ports.

In our country, aeronautic post-war development largely took the form of air mail service, operated first by the Government and subsequently by private contractors. The first successful experiment in regular cross-country night flying was instituted by our Post Office Department between Chicago and Salt Lake City in 1924. Besides establishing lighted airways, the Department also provided advance weather service by radio telegraph between landing fields.

These substantial advances in aerial transportation brought out more strongly than ever before the need for better navigation facilities, as upon these depended the betterment of flying schedule reliability and the reduction of the hazards associated with unfavorable weather.

Recognizing this need, under the Air Commerce Act of 1926 establishing commercial airways, Congress provided funds to develop and maintain aids to navigation on the airways. Accordingly, shortly after its formation in July, 1926, the Aeronautics Branch of the Department of Commerce began a program of establishing aids to navigation on the nation's airways. The aids determined upon were: upper air weather information, airways lighting for night flying, and radio aids. It was recognized that radio offered important advantages in the way of communication between the ground and air and also direct navigational assistance. As there had been little or no experience in the use of radio under the conditions of flight on the civil airways in the U. S. (the Air Mail Service did not employ radio on its airplanes), it was not immediately evident what form these radio aids should take.

A research division of the Aeronautics Branch was organized in the Bureau of Standards to undertake the necessary experimentation and development in this field. It is the development work so far done under the Act that this paper describes.

Early Work

As already mentioned, radio communication between aircraft and ground received some development during the war. Such communication is a powerful aid to air navigation, since in conditions of storms or poor visibility the pilot can be informed of

conditions along his route or told where a landing can be most safely effected. The first attempts to develop a radio device as an actual navigation instrument involved the direction finder, which had been developed and used with great success in marine navigation. It was not possible to duplicate this success in air navigation. Engine ignition system interferences, limited space, excessive noise, and preoccupation of the pilot diminish the probability of taking useful bearings on airplanes with direction-finding coils. Even the use of schemes[1] whereby a bearing could be taken by comparing head telephone signals of equal intensity do not escape these disadvantages. There have been instances[2] of successful use of direction finders on airplanes, but the disadvantages mentioned are inherent.

The reverse procedure[3] (use of direction finder on the ground) is employed successfully abroad, as previously mentioned. However, only aircraft having complete transmitting and receiving sets can receive aid from this system. This eliminates the small airplane. Furthermore, errors in the bearings taken are apt to result with this system owing to the inclination of the airplane transmitting antenna.[4]

The next effort to develop a radio navigational device was the development by the Bureau of Standards of a special type of radio beacon in 1921. Working on the air navigation problem at the request of the Army Air Service, the Bureau devised the crossed-coil or double-beam directive type of radio beacon.[5] This beacon consists essentially of two separate coil antennas, set at an angle with each other, which send signals at alternate intervals. Equality of signal strength from the two antennas is obtained along a line bisecting the angle between the planes of the two antennas. The advantage of the system is that its use requires nothing more than a radio receiving set on the airplane.

In the early work a switch was used to throw the radio-frequency power from one antenna to the other.[5] Tests made at

[1] "Direction Finders for Aircraft," J. Robinson; *Wireless World*, **7**, p. 475; 1919.

[2] "Use of Radio in Airplanes," P. Franck; *L'Onde Electrique*, **2**, p. 200; 1923; **7**, p. 109; March, 1928.

[3] "Wireless Bearings from the Air." *Wireless World and Radio Review*, **18**, pp. 866–868; June 30, 1926.

[4] "Stationary and Rotating Equisignal Beacons," W. H. Murphy and L. M. Wolfe. *Journal* Society Automotive Engineers, **19**, p. 209; September, 1926.

[5] "A Directive Type of Radio Beacon and its Application to Navigation." F. H. Engel and F. W. Dunmore, Bureau of Standards Scientific Paper No. 480, 1923.

Washington on the ground and on ships showed that a course was effectively marked out, permitting navigation without aid of landmarks, compass, or other navigational device. The apparatus was next set up at Dayton, Ohio, and tests made in the air. The method was successful in airplane flights, and had the important advantages that it required no special apparatus to be carried on the airplane and that no error was introduced by wind drift.

In the following four years, the Army engineers at Dayton, Ohio, developed the beacon further[4]; in particular, they devised a signal-switching arrangement such that the signals from the two antennas merge into a steady dash when on the course, giving an added criterion besides that of equal signal intensity to enable the observer to tell whether he is on or off the course. They also introduced a goniometer, or mutual inductance device, to permit orienting the course in any desired direction without moving the antennas.

Recent Work

Under the stimulus of the Air Commerce Act, the Bureau of Standards again undertook this field of investigation in 1926, this time for the newly formed Aeronautics Branch of the Department of Commerce. As a first step, a conference was called June 22, 1926, to secure information and advice from various organizations which had experience bearing on these problems. As a result of its recommendations the development of radio aids for the airways of this country was immediately begun, the principal features to be radio telephony from ground to aircraft, and a radio beacon system.[6] One of the major considerations in narrowing the choice of radio aids to these two was the idea of minimizing the apparatus which would have to be carried aboard the airplanes. The system adopted requires only a simple receiving set to be carried by an airplane. With this set it receives radio telephone information on weather conditions, etc., and also the radio beacon signals to guide it along its course. All of the complicated and expensive apparatus is on the ground at the transmitting end, to be maintained by the Government.

During 1926 and 1927 the Bureau established two experimental radio telephony and beacon stations to carry on its work,

[6] "Applications of Radio in Air Navigation," J. H. Dellinger. *Engineers and Engineering,* 43, p. 301; Nov. 1926; *Mechanical Engineering,* **49,** p. 29; Jan., 1927.

one at College Park, Md., and one at Bellefonte, Pa. The latter was chosen so that practical radio test flights and service flights could be undertaken over a difficult sector of the transcontinental airway.

Interlocking Type of Directive Beacon

A simplified circuit arrangement of the beacon is shown in Fig. 1. A 50-watt master oscillator with two 250-watt amplifier tubes supplies power to two loop antennas. A 500-cycle generator supplies plate power. With this arrangement coil antennas of a type capable of rotation are used to permit orientation of the course.

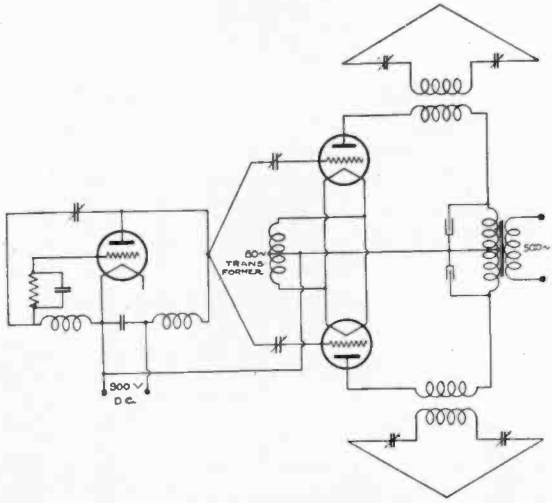


Fig. 1.—Diagram of Elementary Directive Beacon Circuit Employing Rotating Loop Antennas.

While some of the first beacon set-ups employed quenched-spark sets to provide the radio-frequency power, the College Park beacon started from the first with vacuum-tube equipment.

To permit orientation of the course in any direction when large fixed antennas are used, the circuit arrangement shown in Fig. 2 was set up at College Park. This is substantially the arrangement developed by the Army engineers. A four-coil goniometer was interposed between the amplifier plate circuits and the antennas, so that the currents in these antennas due to the driving voltage of one primary goniometer coil would create a resultant field corresponding to that which would be produced

by an imaginary or phantom loop rotating with the primary coil. Two such phantom loops, rotating as the two primary goniometer coils rotate together, set up the course or equisignal zone and allow it to be oriented at any angle without any variation in the field intensity produced.

Fig. 2 also shows the circuit arrangements for the sending of the interlocking signal. As the cams rotate slowly, ampli-

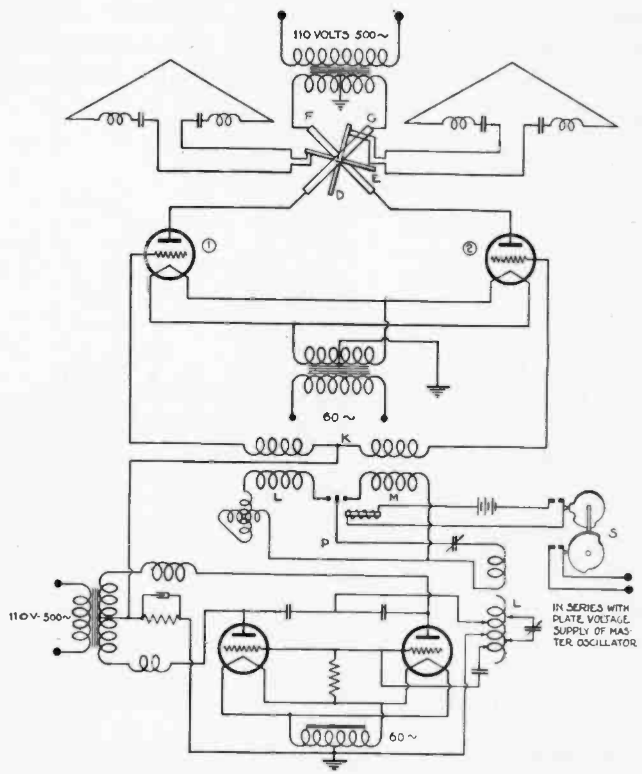


Fig. 2.—Diagram of Interlocking Signal Type of Directive Beacon Circuit Equipped with Fixed Loop Antennas and Goniometer.

fier tube 1 is excited with the Morse letter *A* and amplifier tube 2 with the letter *N*. The two are so interlocked that if the outputs of both amplifiers were fed into a common circuit only a long dash would result. It is to be noted that tubes 1 and 2 never receive any grid excitation simultaneously. An observer located on a line bisecting the angle between the two phantom loops, receiving signals of equal amplitude from each loop, would

therefore hear only long dashes. Were he not on such a line, then he would hear a preponderance of either letter *A* or *N* depending upon the distance away from the line.

Fig. 3 shows a diagrammatic representation of the interlocking signal for different angular positions around the beacon. As might be concluded from inspection of this diagram, some training and skill are necessary to determine direction sharply by listening to these signals.

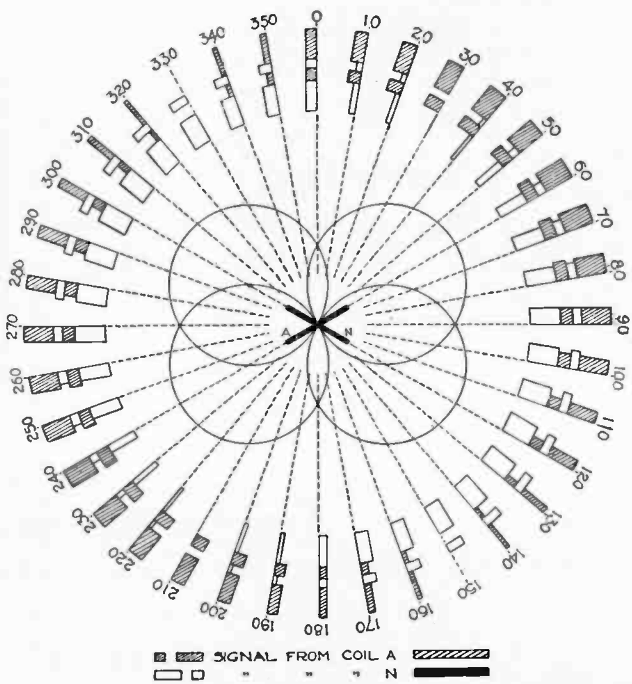


Fig. 3.—Interlocking Characteristic of Equisignal Radio Beacon, Showing Change in Relative Intensity of the Two Signals Received on an Airdraft Flying around the Beacon.

The diagram of Fig. 4 shows further refinements and simplifications resulting in a circuit which has been in use for practical test flying for nearly a year. Small relays serve to provide the interlocking through control of grid current. The master oscillator uses one 250-watt tube and the amplifiers two 1000-watt tubes. The type of goniometer used is shown in Fig. 5. It has two rotors each wound with 8 turns of No. 12 bare copper wire and two stator coils each wound with 32 turns of insulated wire.

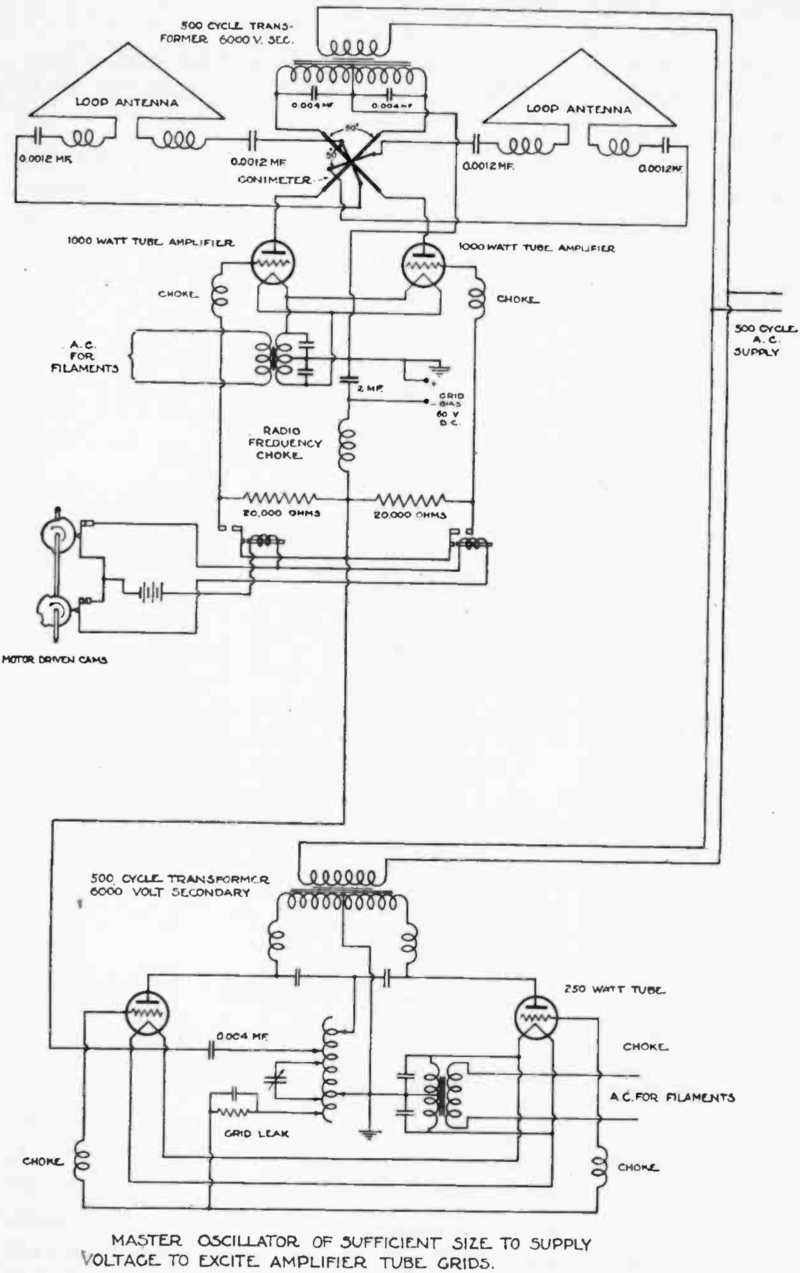


Fig. 4.—Improved Directive Beacon Circuit Diagram Showing Connections of Interlocking Mechanism.

The stator coils are the primary input coils from the amplifier tube plate circuits. It is because this gives a more simple mechanical design that the secondary coils are the ones capable of rotation. With this construction, therefore, the phantom loops revolve in the opposite direction to the revolution of the rotor coils, and care must be exercised to engrave and mount the indicating dial to take that fact into account.

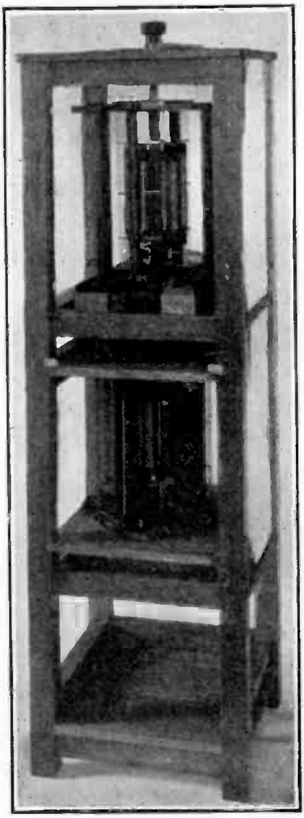


Fig. 5.—Double Rotor Type of Goniometer Used with Modulation Type Directive Beacon.

A number of disadvantages are inherent in the aural interlocking beacon system as described, and the Bureau undertook to investigate these and seek measures for improvement. The obvious advantage of having a visual indicating instrument rather than using the aural (telephone receiver) method made the development of a visual system the first objective. Another ob-

jective was the reduction or elimination of apparent errors in the observed course due to slanting airplane antennas and other causes.

Several methods of operating a visual device for a directive beacon system have been tried. The Army Air Corps worked out a sequence relay arrangement whereby the letter *A* of the interlocking signal would light a red lamp on the airplane instrument board, the letter *N* a green lamp, and the interlocked dash a white light. This system has not been found practical because of the complications of the special apparatus and its

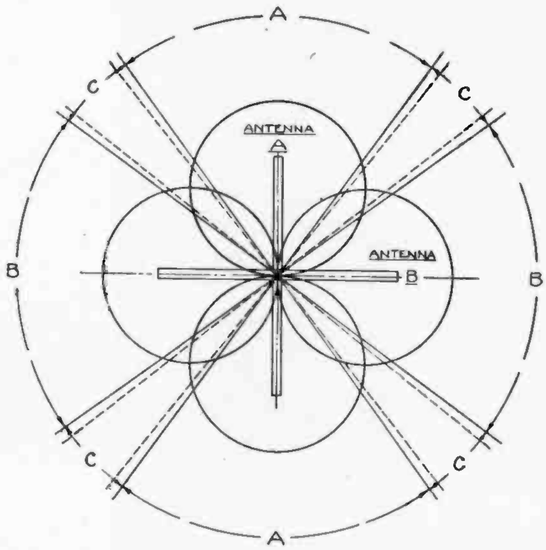


Fig. 6.—Field Intensity Distribution Diagram for Early Type of Modulation Beacon System.

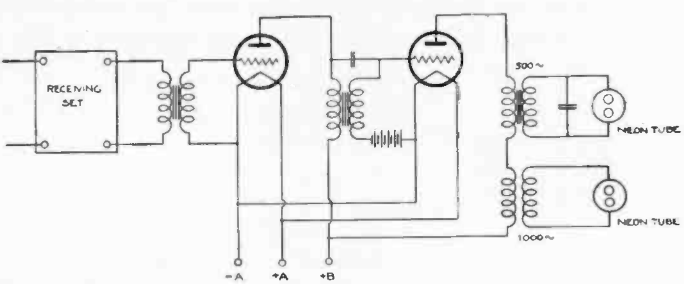
weight, and also the disadvantage that it indicated only whether the airplane was on or off the correct course, giving no information as to how far off it might be.

Modulation Type Beacon

The Bureau attacked the problem of visual indication from another angle. It was determined to try the possibilities of energizing both antennas simultaneously and modulating each by a different audio frequency. Means for separately selecting these modulated frequencies in the receiving set would permit the operation of some indicating device.

As a first step in this development, a method was tried which required only a single source of audio-frequency modulation. Reference to Fig. 4 shows that if both amplifier tube grids receive excitation from the master oscillator simultaneously, power can be supplied to both loop antennas together. Owing to the method of supplying plate voltage whereby plate current flows only when the audio-frequency alternating supply voltage is positive, radio-frequency current flows in only one antenna at any given time.

An observer, therefore, exploring the field around a beacon station so connected and excited from a 500-cycle alternator, will encounter, as indicated in Fig. 6, two wide zones *A* where signals of 500-cycle pitch from loop antenna *A* will be heard. Similar signals will be heard in two other wide zones *B* from loop



F g. 7.—Circuit Diagram for Visual Indicator Using Glow Lamps.

antenna *B*. In four other narrow zones *C*, signals of 1000-cycle pitch will be heard, due to the combined presence of approximately equal signals from both loop antennas. Since the audio-frequency modulation of one antenna lags one-half cycle behind that of the other, the two received together produce the 1000-cycle pitch. If the observer moves from a zone *C* to either zone *A* or *B*, he finds a location where the amplitude of the received 500-cycle current equals that of the 1000-cycle. The eight dotted lines indicate the location of the eight places where such equality exists.

It was thought that if a suitable visual device could be developed to indicate when equality of the 500- and 1000-cycle currents was present, then these dotted lines would constitute radio courses. Such a beacon transmitter contained the very desirable feature of simplicity, particularly as with a push-pull connection of two tubes in the master-oscillator circuit the same

alternator could be used for all tubes, grid excitation voltage in this way being present whenever either amplifier tube plate is positive.

Two visual methods were attempted. Fig. 7 shows a neon lamp device. The output of a receiving set was fed into two selective circuits containing the lamps. Both lamps lighted indicated the position of the course location. One lamp lighted meant off course on the side corresponding to the frequency used to light it. This method was abandoned after several trials because of the need for too many amplifiers to operate the lamps, nor could the distance deviated from the course be told as the lamps were either lighted full or not at all.

Fig. 8 shows the other visual scheme tried. Here the selected audio-frequency currents are rectified and the direct-current outputs connected opposed to a center zero d.c. microammeter. The needle stands balanced at zero with equality of the 500-

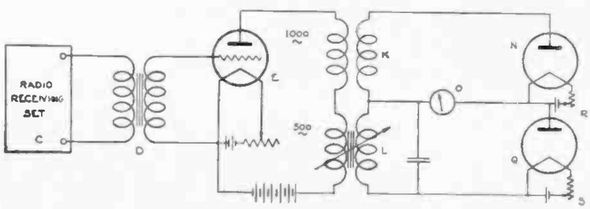


Fig. 8.—Circuit Diagram for Visual Indicator Using Zero Center Microammeter.

and 1000-cycle currents, with a swing in the appropriate direction resulting from "off course" positions. The observer here could estimate his distance off course, but a new disadvantage arose. If all is well and the airplane is flying on the course with balanced needle at zero, the beacon might accidentally stop without the pilot becoming aware of it. This actually occurred twice during test flights near College Park.

Although much work was done on this visual system, it was finally laid aside as impractical because of serious inherent defects. Unduly special receiving circuits were needed. The course could be shifted while flying by changing the radio-frequency tuning, thereby changing the relative magnitudes of the side-band amplitudes corresponding to the 500- and 1000-cycle currents. Frequent rebalance of the rectified currents through the microammeter was necessary. And last but not least, eight courses around a beacon, with pairs of them only a few degrees apart,

proved to be very confusing to the pilots who had opportunity to try it, constituting an arrangement which might have an element of danger.

It was therefore decided to try a system in which two independent modulation frequencies are supplied in the beacon transmitter. This system results in four instead of eight courses, as shown in Fig. 9. To eliminate the wide sidebands of the previous system, low modulation frequencies seemed desirable. It then became possible to use a very simple vibrating steel reed as an indicator. On the airplane the receiving set output is fed to the indicator consisting of small electromagnets between which two vibrating polarized steel reeds are mounted. The reeds are tuned mechanically to the frequencies of the beacon modulation voltages.

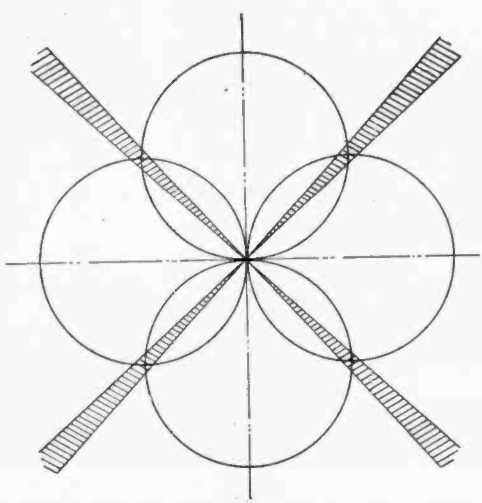


Fig. 9.—Field Intensity Distribution Diagram for Modulation Type of Beacon.

Simplicity of operation has resulted. An ordinary receiving set, with the small reed unit which weighs less than an ordinary pair of head telephones, constitutes the airplane radio equipment. The reeds vibrate with equal amplitude when on the course. When off the course, the observer can estimate the distance he is off by noting the relative reed amplitudes. An advantage of the system is that if the beacon ceases to function the observer is aware of it, whether he is on or off course. A still more important advantage is that, owing to the sharp mechanical tuning

of the reeds, they are immune to interference that would entirely ruin aural reception, unless the interference is of such strength as to overload completely the receiving set.

Beacon Transmitting Apparatus

The first practical attempt to produce workable signals was carried out with a master oscillator operating with a direct-current plate supply. One of the amplifiers was supplied with plate power from a transformer connected to the commercial 60-cycle supply line, and the other amplifier supplied with 86 cycles obtained from a small alternator. Two reeds tuned to these

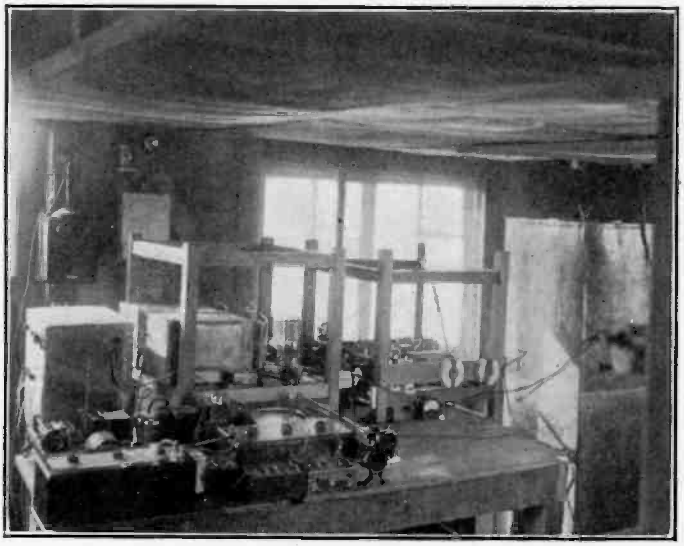


Fig. 10.—Temporary Beacon Apparatus for Modulation System, Installed at College Park, Md.

frequencies were made up and full scale deflections were obtained at a distance of ten miles with a suitable receiving set. Upon trial in flight an observer equipped with reeds tuned to these modulating frequencies experienced no difficulty in guiding the airplane by giving instructions to the pilot.

It was observed when making a field intensity survey of signals from this beacon, that symmetrical figure-eight patterns were not secured when the stator coils were set at right anles to each other. It was found necessary to set the stator coils that

there would be no inductive coupling between them. Some of these effects appeared due to couplings between different parts of the system. It was also found that a more steady source for the low-frequency currents would be needed. The commercial power supply frequency varies in Washington as much as ± 0.15 cycle while the reeds required steadiness within ± 0.05 cycle.

It was accordingly decided to secure the low frequencies from two vacuum-tube driven tuning forks and then modulate the 290-kc carrier in the two respective amplifier branches from these using either grid or plate modulating methods. The system was therefore set up in this way using d.c. plate power supply throughout, though at first vacuum-tube oscillators were employed instead of tuning forks. Their frequencies were held sufficiently steady by hand-operated trimming condensers so they could be used for experimental purposes. Fig. 10 shows the first temporary setup of apparatus at College Park. Fig. 11 shows the circuit arrangement. The master oscillator employs a 7.5-watt tube. This supplies grid voltage for both of the first tubes of the two sets of amplifiers, which are also of 7.5-watt size. Following this is a stage consisting of two 50-watt tubes in parallel followed by a single 1000-watt tube. Voltage from the low-frequency oscillators marked *A* and *B* in Fig. 11, which also use a 7.5-watt tube each, is applied in each case to the grids of two 7.5-watt modulator tubes connected to the plate of the 7.5-watt radio-frequency amplifier tube in the usual Heising fashion. A goniometer of different design was also introduced, having two sets of rotor coils in series, each set being in the field of one of the stator coils. The purpose of this construction was to separate the stator coils and reduce coupling between them.

Upon investigation many stray capacitive couplings were found in the system. For example a 10 to 15 per cent capacitive coupling was found to exist between the stator coils due to their position with respect to each other. A like amount was found between the stator coils due to the couplings between them and the common rotor system which, while it did not manifest itself as a coupling between the stators, resulted in capacity currents flowing out through the rotor coils into the horizontal portions of the loop antennas. These currents, being of different phase from those normally flowing, introduced errors and dissymmetry. These couplings were largely overcome by placing copper

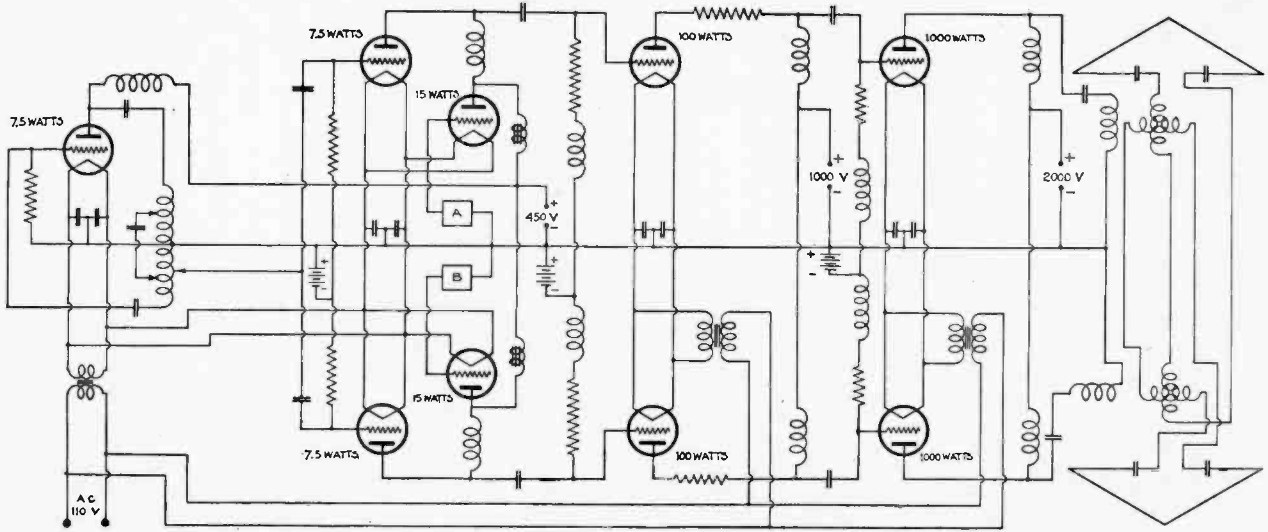


Fig. 11.—Circuit Diagram of Double Modulation Type of Beacon.
A and *B* are tuning-fork generators of modulation frequencies.

screens between and around the stator coils, and grounding both rotor systems at their center point so that capacity currents leave the system by that return instead of via the antenna wires. It was also found necessary to shield carefully all the amplifier stages as well as the master oscillator, and introduce choke coils with bypass condensers at strategic points so as to prevent cross couplings between the two amplifier systems.

Some remarks concerning the field patterns produced by this system may be of interest. In vector diagram, Fig. 12

E_{S_1} is voltage across upper stator coil S_1 of goniometer
E_{S_2} is voltage across lower stator coil S_2 of goniometer

$E_{R_1'}$ is voltage in upper rotor coil R_1' of goniometer
$E_{R_1''}$ is voltage in lower rotor coil R_1'' of goniometer
} connected in series with antenna 1.

$E_{R_2'}$ is voltage in upper rotor coil R_2' of goniometer
$E_{R_2''}$ is voltage in lower rotor coil R_2'' of goniometer
} connected in series with antenna 2.

S_1 and S_2 are at right angles to each other
R_1' and R_1'' are in the same plane.
R_2' and R_2'' are in a plane at right angles to rotors R_1.
P is the position of the observer considered to be in the horizontal plane containing the radio station.

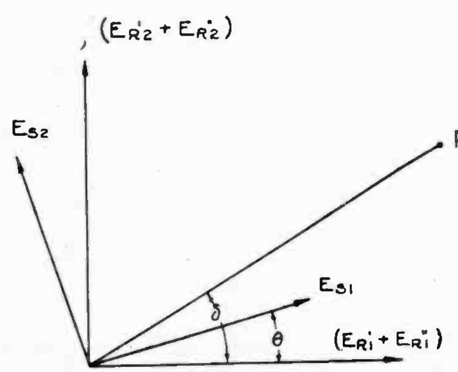


Fig. 12.—Vector Diagram of Goniometer and Antenna Currents.

For the sake of clarity, since the rotor currents are the same as the antenna currents, and the antennas are fixed in space, this treatment can be simplified by considering the stator coils

as the ones rotated. This has not been done with the equipment because of mechanical reasons, a better structure resulting when the antenna coils are the ones capable of rotation.

Whenever observer P is in such a location that he obtained equal field intensities from the two phantom beacon antennas, and these intensities become unequal as the observer moves away transversely in either direction from the place of equality, then a radio course can be said to exist.

The field intensity at P will be

$$E_p = K\left[(E_{R_1'} + E_{R_1''}) \cos \delta + (E_{R_2'} + E_{R_2''}) \sin \delta\right] \tag{1}$$

The rotor voltages will be

$$E_{R_1'} = AE_{S_1} \cos \theta$$

$$E_{R_1''} = AE_{S_2} \cos (90 + \theta)$$

$$E_{R_2'} = AE_{S_1} \sin \theta$$

$$E_{R_2''} = AE_{S_2} \sin (\theta + 90)$$

The antenna voltages will be

$$E_{R_1'} + E_{R_1''} = AE_{S_1} \cos \theta - AE_{S_2} \sin \theta \tag{2}$$

$$E_{R_2'} + E_{R_2''} = AE_{S_1} \sin \theta + AE_{S_2} \cos \theta \tag{3}$$

where K and A are constants.

Combining equations (1), (2), and (3) and simplifying

$$E_p = AK\left[E_{S_1} \cos (\theta - \delta) - E_{S_2} \sin (\theta - \delta)\right] \tag{4}$$

This shows that for any fixed position of the coils, the field pattern will be two cosine curves at right angles to each other, as polar functions of angle δ.

The field intensity observed at a fixed point P varies in the same manner as the coils are rotated. If no modulation is impressed on either amplifier system, and taking

$$E_{S_1} = E_{S_2} = E_S$$

$$E_p = AKE_S\sqrt{2} \sin\left(\theta - \delta - \frac{\pi}{4}\right) \tag{5}$$

The existence of such a single figure-of-eight pattern which rotates when the coils are turned was verified by observation.

Of interest is the situation when one rotor coil is reversed. The vector diagram of Fig. 13 applies. Here equation (3) must be written

$$E_{R_2'} - E_{R_2''} = AE_{S_1} \sin \theta - AE_{S_2} \cos \theta \tag{6}$$

and equation (4) becomes

$$E_p = AK[E_{S_1} \cos(\theta - \delta)] - E_{S_2} \sin(\theta + \delta) \qquad (7)$$

In this case when the coils are rotated the cosine and sine field intensity patterns revolve in opposite directions, and the course cannot be oriented where desired. It lies on the same axis at all times. This relation can be written in another form taking the case of no modulation, with

$$E_{S_1} = E_{S_2} = E_S$$

$$E_p = AKE_S(\cos\theta\cos\delta + \sin\theta\sin\delta - \sin\theta\cos\delta - \cos\theta\sin\delta)$$

$$= E_p = 2AKE_S \cos\left(\theta + \frac{\pi}{4}\right) \sin\left(\delta + \frac{\pi}{4}\right) \qquad (8)$$

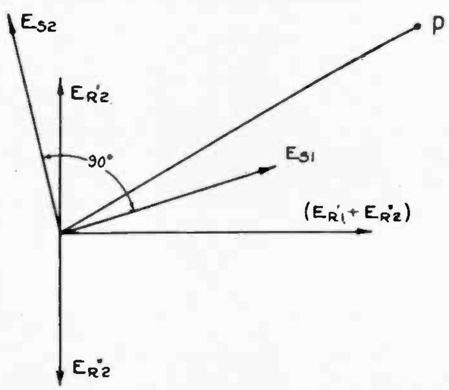


Fig. 13.—Vector Diagram of Goniometer and Antenna Currents with One Secondary Coil Reversed.

Here it can be seen that the only effect of changing the angular position of the coils, which means a change in θ, is to control the amplitude of the sine curve field intensity pattern. When $\theta = \frac{\pi}{4}$ or $\frac{5\pi}{4}$ no external field exists as E_p is zero. At angles $\theta = \frac{3\pi}{4}$ and $\frac{7\pi}{4}$ the two components of the field are in phase and no course exists in the sense as defined above.

Care must therefore be taken when connecting up an arrangement of this kind, not to get one rotor coil reversed. This can be very easily checked by noting the antenna currents. When correctly connected the antenna currents, resulting from the voltages expressed by equations (2) and (3), are such that when

there is a rise in one, a fall occurs in the other when the goniometer is rotated. If incorrectly connected the currents are as expressed in equations (2) and (6) and rise and fall together as the goniometer is turned.

So far we have assumed resonance in the antennas with voltages and currents in phase. This has permitted the writing of a direct relation between field intensity and stator coil voltage. Another matter of interest, therefore, is what occurs when these antenna currents are out of phase. Such a condition can occur from several causes, but the most likely one from a practical standpoint is that due to the antenna circuits getting out of tune.

The loop antennas at College Park operate at 290 kc and are tuned with condensers of 0.0006 μf in series. The total loop

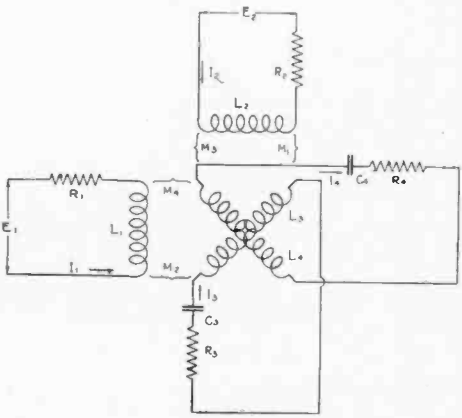


Fig. 14.—Circuit Relations in Goniometer—Antenna System.

resistance is about 8 ohms. If the capacity of one loop were increased and that of the other decreased a like amount, reducing the loop currents to $\frac{1}{\sqrt{2}}$ (their normal values) then these currents would be in quadrature. This would result in a rotating field and the field intensity would be the same at every point around the beacon in the case of no modulation. For a phase difference of less than 90 deg. the locus of the rotating vector would be elliptical and the pattern of field intensity would have two minima which become less sharply defined as the phase difference increases. Observations taken by means of a thermoelement at a distant receiving point, as the goniometer is rotated, can

thus be used as a ready check upon the equality of phase adjustment of the antenna currents.

With modulation impressed on the two antenna currents, no difficulty is encountered by reason of a phase displacement, provided each modulating frequency is entirely confined to its own antenna.

The matter of inequality of these phase angles, however, is important, as it introduces reaction back into the primary coil circuits. Referring to Fig. 14, L_1 and L_2 are the input goniometer coils, and L_3 and L_4 those connected to the antennas. As the two input circuits are identical with the same voltage impressed on each of them, we can put

$$M_1 = M_4 = M\cos\theta$$

$$M_2 = M_3 = M\sin\theta$$

$$R_1 + j\omega L_1 = R_2 + j\omega L_2 = Z$$

$$R_4 + j\left(\omega L_4 - \frac{1}{\omega C_4}\right) = Z_4$$

$$R_3 + j\left(\omega L_3 - \frac{1}{\omega C_3}\right) = Z_3$$

The following relations can be written

$$E_1 = I_1 Z + j\omega M I_4 \sin\theta + j\omega M I_3 \cos\theta \tag{9}$$

$$E_2 = I_2 Z + j\omega M I_4 \cos\theta + j\omega M I_3 \sin\theta \tag{10}$$

$$0 = I_3 Z_3 + j\omega M I_1 \cos\theta - j\omega M I_2 \sin\theta \tag{11}$$

$$0 = I_4 Z_4 + j\omega M I_1 \sin\theta + j\omega M I_2 \cos\theta \tag{12}$$

From (11) and (12) we get

$$I_3 = \frac{j\omega M}{Z_3}(I_2 \sin\theta - I_1 \cos\theta) \tag{13}$$

$$I_4 = \frac{j\omega M}{Z_4}(I_2 \cos\theta - I_1 \sin\theta) \tag{14}$$

If the impedances Z_3 and Z_4 are made equal, the antenna currents will be in phase. This condition is fulfilled when both circuits are in resonance, and the values of I_1 and I_2 become after placing values for I_3 and I_4 in (9) and (10)

$$I_1 = \frac{E_1}{Z + \dfrac{\omega^2 M^2}{Z_0}} \tag{15}$$

$$I_2 = \frac{E_2}{Z + \dfrac{\omega^2 M^2}{Z_0}} \tag{16}$$

where Z_0 is the antenna impedance, or in the case of resonance its resistance. Here the values of currents I_1 and I_2 are independent of the coil angle. It can be seen in this case that the current in each primary circuit is due only to the applied voltage of its own circuit.

If $E_1 = E_2 = E$ and Z_3 is not equal to Z_4 in which case the antenna currents are not in phase, the solutions for I_1 and I_2 are

$$I_1 = E \frac{\left(Z + \dfrac{\omega^2 M^2}{Z_4}\right) + \dfrac{\omega^2 M^2}{2}\left(\dfrac{1}{Z_3} - \dfrac{1}{Z_4}\right) + \dfrac{\omega^2 M^2}{\sqrt{2}}\left(\dfrac{1}{Z_3} - \dfrac{1}{Z_4}\right)\sin\left(2\theta - \dfrac{\pi}{4}\right)}{\left(Z + \dfrac{\omega^2 M^2}{Z_4}\right)\left(Z + \dfrac{\omega^2 M^2}{Z_3}\right)} \tag{17}$$

$$I_2 = E \frac{\left(Z + \dfrac{\omega^2 M^2}{Z_4}\right) + \dfrac{\omega^2 M^2}{2}\left(\dfrac{1}{Z_3} - \dfrac{1}{Z_4}\right) + \dfrac{\omega^2 M^2}{\sqrt{2}}\left(\dfrac{1}{Z_3} - \dfrac{1}{Z_4}\right)\sin\left(2\theta + \dfrac{\pi}{4}\right)}{\left(Z + \dfrac{\omega^2 M^2}{Z_4}\right)\left(Z + \dfrac{\omega^2 M^2}{Z_3}\right)} \tag{18}$$

and it can be seen that these currents vary with the angular position of the goniometer primary and secondary coils to each other showing that one primary circuit reacts on the other primary circuit by way of the antenna circuits.

If E_1 and E_2 are each modulated to one of the desired low frequencies, such as 65 and 86 cycles, the expressions for I_1 and I_2 become much more complicated and I_1 will contain a component due to voltage E_2, and I_2 likewise will have a component due to voltage E_1, for all values of angle θ except certain multiples of $\frac{\pi}{4}$. This situation is equivalent to that produced by coupling between the amplifier systems which introduce distortion in the output characteristic. The maintenance of resonance in both the antennas therefore constitutes an important operating condition.

Receiving Equipment

The only airplane antenna system that has been found effective heretofore is the weighted trailing wire. This, generally speaking, has marked directive properties[4] so that unless it lies in the plane containing the transmitting station, erroneous indica-

tions of the beacon course are received.[7] When near the beacon so that the vertical angle of the airplane position is appreciable, further errors arise. The trailing wire antenna is annoying to handle and also dangerous, and when made of large substantial material hangs at a still more unfavorable angle.

Were it possible to receive sufficient signal strength, a short trailing wire about 20 ft. long would suffice and would have some advantages, as tests show that with a proper stream-lined weight an antenna of this length will hang nearly vertically even with a heavy wire.

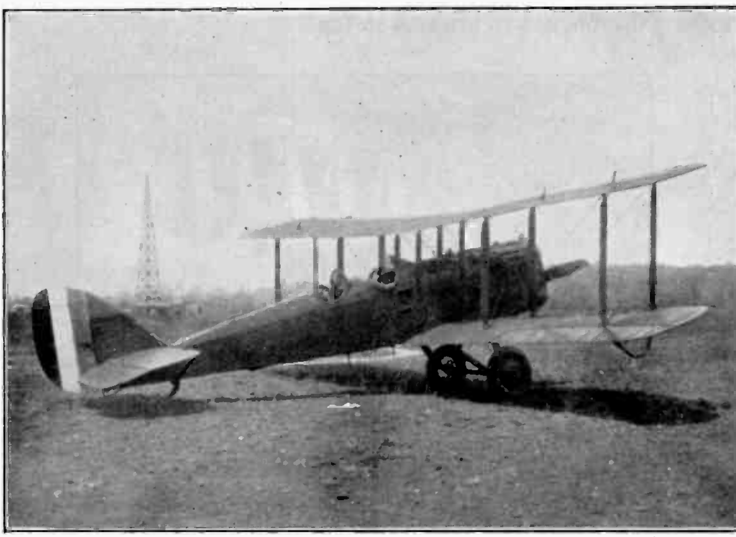


Fig. 15.—Airplane with Vertical Pole Antenna Installed.

Receiving sets have been developed of a sensitivity sufficient to use such an antenna effectively, developing an output at the modulated frequencies of about 10 volts. This gives satisfactory reception of the beacon signals at a distance of 100 miles with 10 amperes antenna current fully modulated.

To simplify further the airplane antenna structure, flight tests were made with a vertical metal pole ten feet high mounted on the airplane. (See Fig. 15). Used in conjunction with specially designed receiving sets described below, this type of antenna was

[7] Space Characteristics of Antennae. W. H. Murphy. *Journal* of the Franklin Institute, 201, pp. 411–429, April, 1926; 203, pp. 289–312, Feb., 1927.

found to be very satisfactory from all standpoints. No apparent errors in the beacon courses could be noticed. With the trailing wire it was a very difficult feat to guide an airplane right to the beacon, and it became impossible when a side wind produced a slide slant to the antenna. With the vertical pole antenna it became very simple to fly directly towards the beacon. Furthermore since a horizontal electric field induces no current in the vertical pole antenna and as no vertical field exists directly above the beacon station, there is a cessation of signal at the moment when the airplane passes over it. The beacon can thus be located within 100 feet when the airplane is not over 1000 feet above it, a most valuable aid to landing in fog.

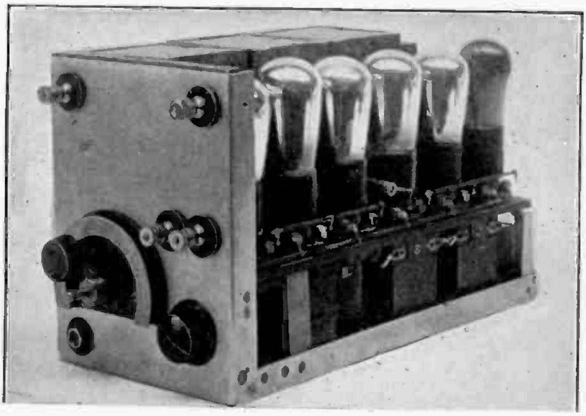


Fig. 16.—Special Receiving Set Developed for Aircraft Reception of Radio Beacon and Telephone Signals.

Receiving sets have been developed for this work which supply ample voltage for operating the visual indicator unit, with a radio-frequency input voltage of as low as 10 microvolts. These sets (see Fig. 16) are equipped with a uni-tuning control to cover the aircraft telephone and beacon frequency bands extending from 285 to 350 kc, allocated by the 1927 International Radiotelegraph Convention. The set has an audio-frequency amplifier which is efficient down to 50 cycles; it weighs from 12 to 16 lbs., depending upon the design. A small panel, mounted in the cockpit or on the instrument board, contains a volume control, battery voltmeter, filament switch, and jack for head telephones. The pilot adjusts the volume control to maintain a convenient amplitude of vibration of the reed indicator.

With sets of this sensitivity, full range of operation cannot be secured without careful engine ignition system shielding. Merely shielding the high and low tension wires is not sufficient. The spark plugs must also be screened. It seems that the advantages of the vertical pole antenna must be purchased at the price of installing spark plug shielding, which entirely eliminates the undesired interference. There is sufficient room on the modern radial type of airplane engine to accommodate spark plug covers, and a successful installation of this kind has been made at College Park. It is expected that suitable spark plugs and shielded wire harnesses to connect with them will be available on the market in the near future.

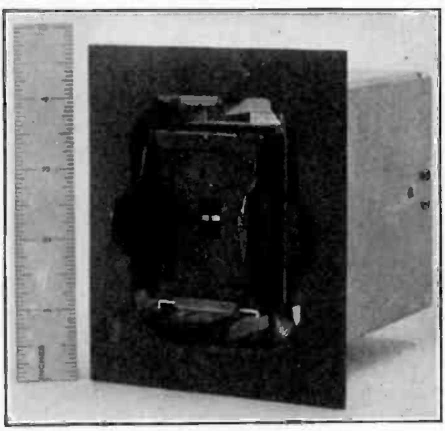


Fig. 17.—Reed Indicator Unit with Spring Holder

Figs. 17 and 18 show one type of reed indicator unit. This unit is designed to match the output impedance of the receiving set, which is between 4000 and 7000 ohms, and gives full scale deflections with from 4 to 10 volts across the terminals. The indicator reeds may be all steel, or may consist of a small steel armature with the principal vibrating portion of elinvar. The latter has the advantage that the reed tuning is practically independent of temperature because the modulus of elasticity of elinvar has a negligible temperature coefficient. When an all-steel reed is used, the effect of temperature in varying the tuning of the reed is such that damping must be provided to make it respond to frequencies over a range of plus or minus at least 0.4 per cent. The damping is introduced by so shaping the reed

as to introduce an appropriate amount of surface moving against the air. With any type of reed some damping is necessary, in order to keep the reed operative in case small variations of frequency occur in the radio beacon transmitting apparatus.

The indicator unit is placed on the airplane instrument board in a shock-proof mounting. The indicator with mounting weighs only about a pound, rather less than a head telephone set which it replaces. This system thus ideally meets the requirement of minimum weight aboard airplanes. The type of indicator shown plugs conveniently into its mounting. The plug-

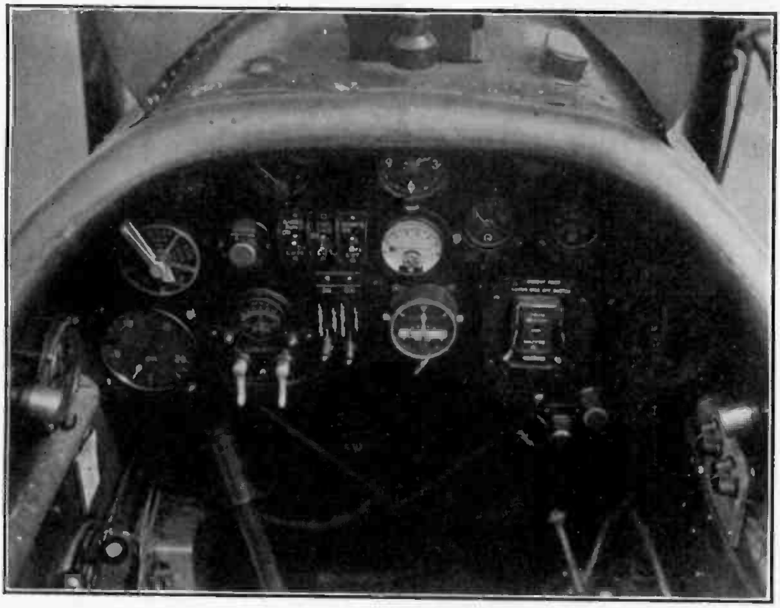


Fig. 18.—Reed Indicator Unit and Holder Mounted on Airplane Instrument Board.

in arrangement has several advantages. It facilitates changing indicators when the airplane is used on a route in which different modulation frequencies are used at the beacon. It is also a convenient practice to reverse the connections of the indicator whenever flying past the beacon by removing the indicator, turning it upside down, and plugging in again. Then the convention as to relative amplitudes of reed vibration remains unchanged. For this reason, the indicator has "From beacon" and "To beacon" engraved at opposite ends of its face.

Direction Variations

The existence of errors at night in the apparent observed direction of radio stations has long been known.[8,9] Their existence in the case of the directive radio beacon of the type described was discovered by one of the authors[10] during test flights made in August, 1927.[11]

Investigations as to the causes of direction shifts have been under way for some time, particularly in England,[12] and experimental proof has been secured that these shifts are due to the horizontal component of the downcoming-reflected or refracted wave. Special experiments made upon our beacon stations have verified this.[11]

As it has been shown and experimentally verified, that the vertical pole type of airplane antenna is immune to horizontal electric fields when correctly installed, it is expected that with it, no night variations of magnitude will be observed.

Practical Applications

By the use of the directive radio beacon, an airplane can be held on a straight course represented by a zone from 2 deg. to 5 deg. wide extending from the beacon station. The equipment described has a reliable day operating range of 100 miles. As can readily be seen, the controlled flight of the airplane along this straight course is independent of wind drift, so that the pilot does not need to take that into account.

However, there is no means whereby the pilot can judge his distance from the beacon, as a head or tailwind may alter the airplane's ground speed. Small marker beacons set at frequent intervals along the directive beacon course will provide this information. Tests have indicated that a 7.5-watt tube oscillator feeding a vertical antenna, both tuned to the same radio frequency on the directive beacon, will have a signal range of less than about

[8] "Variation in Direction of Propagation of Long Electromagnetic Waves," A. H. Taylor, Scientific Paper, Bureau of Standards, No. 353, 1919.

[9] "Some Radio Direction-Finding Observations on Ship and Shore Transmitting Stations. Smith-Rose, R. L. *Journal* I.E.E. (London), 62, pp. 701–711, August, 1924.

[10] Haraden Pratt.

[11] "Apparent Night Variations of Crossed Coil Radio Beacons," H. Pratt. Proc. I. R. E., 16, p. 653; May, 1928.

[12] "The Cause and Elimination of Night Errors in Radio Direction-Finding." R. L. Smith-Rose and R. H. Barfield, *Journal* I. E. E. (London), **64**, pp. 831–843; August, 1926.

three miles. The present modulating frequencies used at the College Park station are 65 and 86 cycles. By supplying the marker beacon oscillator with a plate voltage secured from a commercial 60-cycle supply, a third reed unit on the airplane instrument board tuned to 60 cycles will respond to these markers, and if each marker emits a characteristic signal at an appropriate speed, it may be identified by the pilot. Here again, the marker will have above it a conical region of no signal, made possible by the vertical pole airplane antenna. This will make the marker's location capable of definite determination by the pilot.

The successful reception of a characteristic marker beacon signal with the reeds has demonstrated the feasibility of the sending of intelligence by telegraphic code over the system.

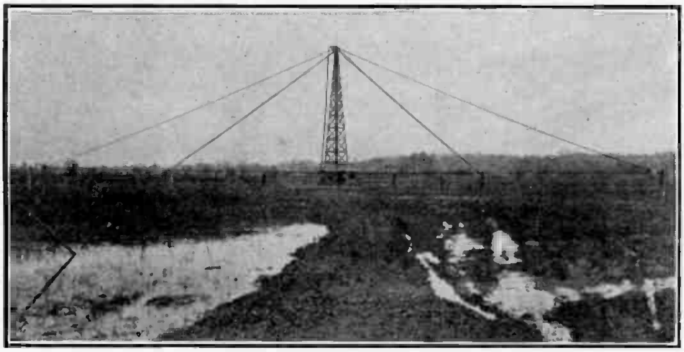


Fig. 19.—Directive Radio Beacon Station of Bureau of Standards, College Park, Md.

Weather information, for example, might be sent using a few simple code groups. Such information can be sent on the reeds provided for the beacon reception, or on one or more special reeds.

It has been found that if the two modulating frequencies of the directive beacon are too nearly alike, the low-frequency beats between them cause the reeds to flutter. This beat frequency must be sufficiently high so that the reed does not have opportunity to store up and dissipate energy in its oscillating state. With the system as now developed, a separation of 20 cycles between the reeds is necessary. This does not permit of more than two or, at the most, three groups of these frequencies to be used on the same carrier frequency in any one neighborhood.

This is not a serious matter as more than two or three groups in one locality will not be needed.

Since the marker beacon frequency of 60 cycles will not have a separation of 20 cycles from the 65-cycle modulation of the directive beacon, and may not have this separation from some other directive beacon frequency which may be in operation in the vicinity, some flutter will occur when very close to the marker. Tests have indicated that the degree of flutter in that case is not of a serious nature as the marker beacons use low power and have a short distance range.

The plugging of a pair of head telephones, or an aviation helmet equipped with telephone receivers, into the output circuit of the receiving set, makes possible the reception of radio telephone messages. The change to the telephone connection involves an adjustment of the unicontrol tuning element on the receiving set at present in use. At the present time the College Park and Bellefonte beacons are adjusted to a frequency of 290 kc and the ground telephone transmitting stations to the new International calling and distress aircraft frequency of 333 kc. Suitable stops on the receiving set tuning control lever adjusted for these frequency settings enable the pilot to make the change from one to the other with a minimum of effort.

With a ground station power of 1 kw, reliable telephone signals have been received on an airplane in flight for a distance of 100 miles. The important limiting factor is the engine ignition interference, as noise from this source that will not influence the reed indicator will create serious interference with the reception of speech. The practical distance range for speech is also somewhat reduced by the presence of a considerable general noise level on the airplane, which is not a factor in the operation of the reed indicator. Experience to date has indicated that a somewhat greater distance range may be expected with the visual indicator than for radio telephony, under similar conditions of power and receiving equipment.

The combination of directive and marker beacons with weather and other information broadcast to airplanes by radio telephony, properly organized, thus provides a complete set of radio aids for air navigation. They permit flying under conditions of no visibility, and should add materially to the safety and reliability of air transportation.

In concluding, the authors desire to acknowledge the parts

played in these developments by their coworkers in the Bureau of Standards. Appreciation of valuable contributions is extended to F. W. Dunmore, particularly for ingenious laboratory developments and basic ideas in connection with the modulation type of beacon and the visual indicator; to Harry Diamond for the design and construction of the airplane receiving sets, and the research incident to the operation of the beacon and its modulating arrangements; and to Dr. E. Z. Stowell for contributions to the earlier circuit arrangements described and studies of the field intensity diagrams. Acknowledgments are also due to Captain Russell L. Meredith, airplane pilot, C. B. Hempel and R. M. Green for field installations and tests, F. G. Gardner, airplane mechanic, and L. L. Hughes, D. O. Lybrand, and R. R. Gessford, who manufactured much of the apparatus used.

AIRCRAFT RADIO INSTALLATIONS*

By

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Summary—*This paper deals in a general manner with the technical aspects of aircraft radio design and installation, and illustrates the trend of development during recent years. Radio conditions and installations aboard dirigibles (lighter-than-air craft) are described and compared with the more severe conditions and requirements aboard airplanes (heavier-than-air craft). The bearing of these special conditions both on receiver and transmitter design is shown, resulting in highly specialized equipment for aircraft use, with several distinct means of power supply. Described and illustrated are also various expeditionary aircraft radio installations, emergency radio equipment, some special high-frequency aircraft radio apparatus, as well as some standard installations in naval planes. Advantages and disadvantages of various directional radio applications for aircraft navigation are shown. The paper concludes with a brief description of recently developed commercial radio equipment, and an enumeration of ground radio facilities being installed by the government; these are expected to have a far-reaching influence on safety and dependability of our rapidly developing commercial air transportation.*

A. Introduction

After a period of rapid growth, aviation today has reached a state where its successful commercial application is as much concerned with development of essential accessories as with improvements in the aircraft itself; thus one of the greatest needs today of commercial air transportation is the provision of simple and accurate means of navigation and of safety in landing under unfavorable flying conditions with poor visibility. The importance of radio communication to aircraft is apparent; its value has been proved not only in many years of application in our military services but also by foreign everyday commercial use, as well as on a number of more or less spectacular long-distance flights. If existing radio possibilities have not been realized or taken advantage of on some otherwise well-prepared flights, this has been due in many cases to lack of information on aircraft radio by the flight organiztion; in some cases, the operating or installation personnel has not

* Original Manuscript Received by the Institute, May 11, 1928.
Presented before Washington Section of the Institute, May 2, 1928.
Presented at New York Institute Meeting, June 6 1928.

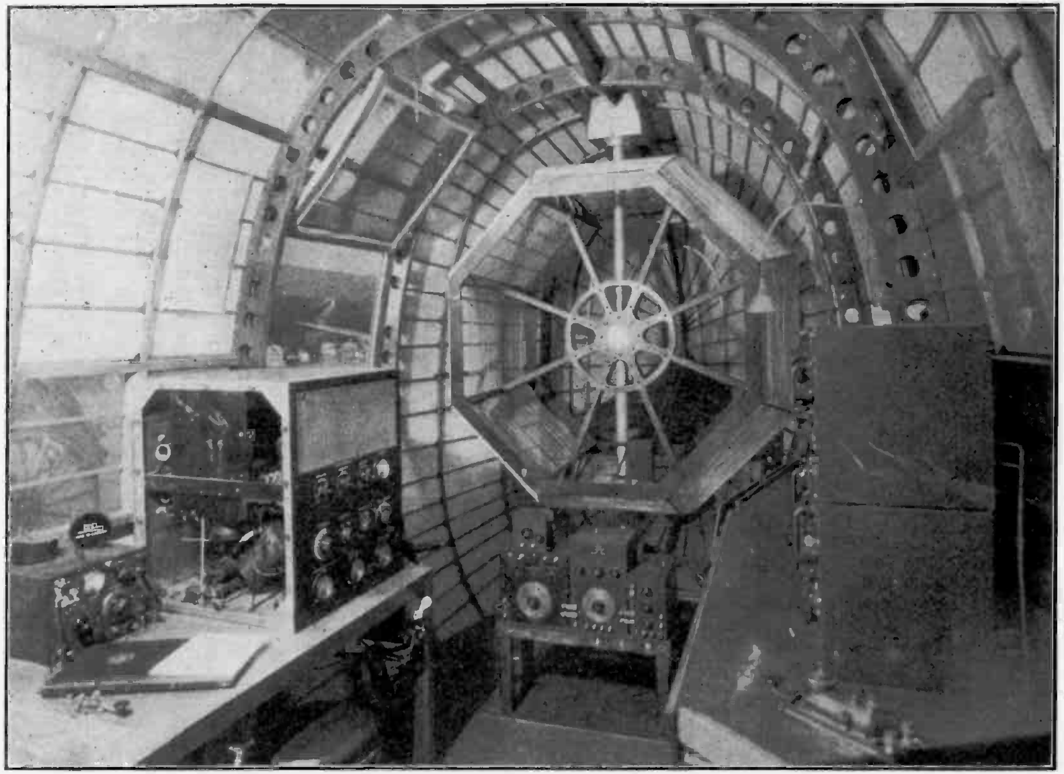


Fig. 1—Looking Aft in Radio Room, USS *Shenandoah*.

been sufficiently competent, or the equipment has been unsuitable. It is surprising how little is known about the special problems and developments of aircraft radio even among professional radio engineers. It is impossible within the scope of this paper to more than touch upon the various requirements and conditions encountered in this large special field, but it is hoped that

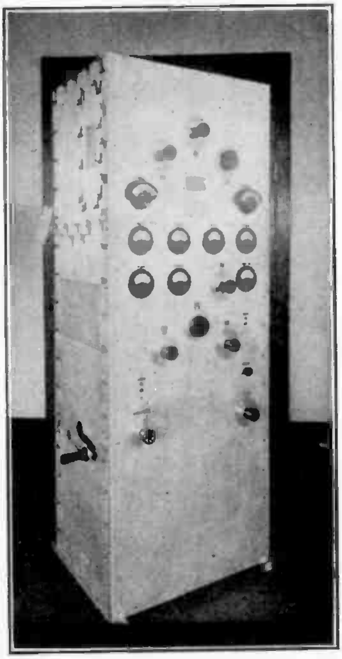


Fig. 2—Front of 2 kw. Transmitter Built for USS *Shenandoah.*

this paper will clear up some past misapprehensions and result in a better understanding of this important application of radio.

B. Radio Equipment for Dirigibles

Conditions met with on aircraft demand that most radio equipment carried be of highly specialized design, both electrically and mechanically, in order to meet the severe requirements imposed. Dirigibles, or airships, so-called lighter-than-air craft, beyond imposing space and weight restrictions on the equipment are relatively free from the detrimental conditions found on heavier-than-air planes; in fact, the height of the radiating system above the energy-absorbing ground together

with the effective low-resistance counterpoise offered by the all-metal framework give the large rigid dirigibles advantages not found on ground or shipboard installations and make possible communication over great distances with radio equipment of necessarily restricted power and weight. Fig. 1 shows a

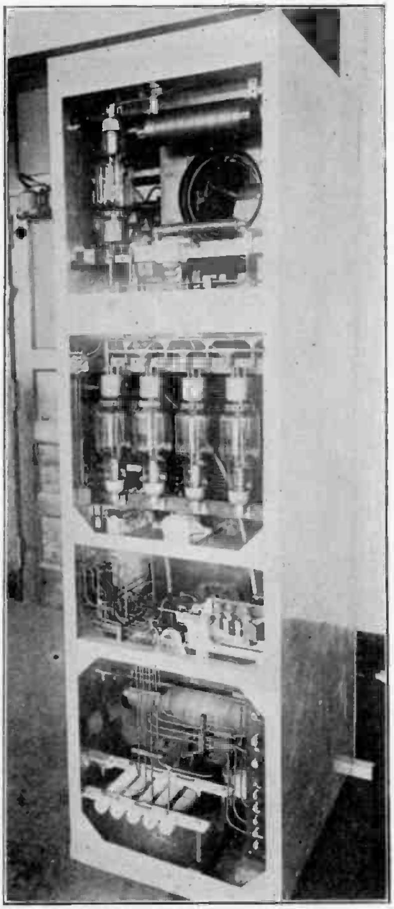


Fig. 3—Right Side of 2 kw. *Shenandoah* Transmitter.

typical installation in a large airship, the rear portion of the radio room in the late USS *Shenandoah*. In order to provide a relatively unshielded location for the radio compass shown in the center of the picture, the radio room was of wood and fabric construction and in this respect differed from the metal framework construction of the remainder of the ship including the control room ahead. Being a part of the forward "car" or gon-

dola, the radio room was well removed from the propelling motors located in the power nacelles, and was correspondingly free from noise and vibration as well as from electrical disturbances in flight. To the right in the picture are shown the intermediate and low-frequency receivers, while the small high-frequency receiver with removable coils is shown at the extreme left. Adjoining this is seen the high-frequency 50-watt transmitter, and under the table at the left are shown the flameproof switch

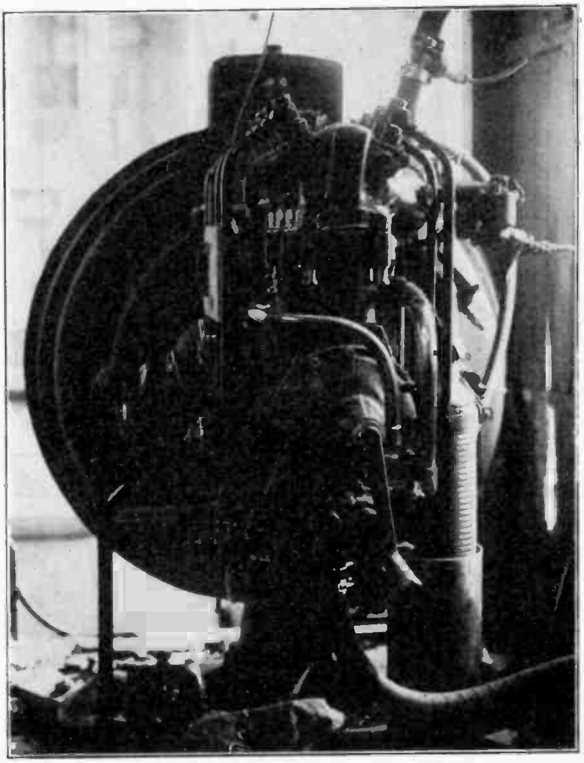


Fig. 4—15 H. P. Gasoline Electric Power Unit for *Shenandoah* Transmitter, Rear View

boxes for the transmitters. The main intermediate frequency transmitter employing six 50-watt tubes is not shown in the picture, being to the left and ahead of the h.f. receiver, it provided for transmission either by plain or modulated C. W. or by voice, with a dependable telegraph range in excess of 500 miles. Power supply for both transmitters was from a dynamotor operated from storage batteries, which in turn were kept charged by means of a gasoline-driven charging generator oper-

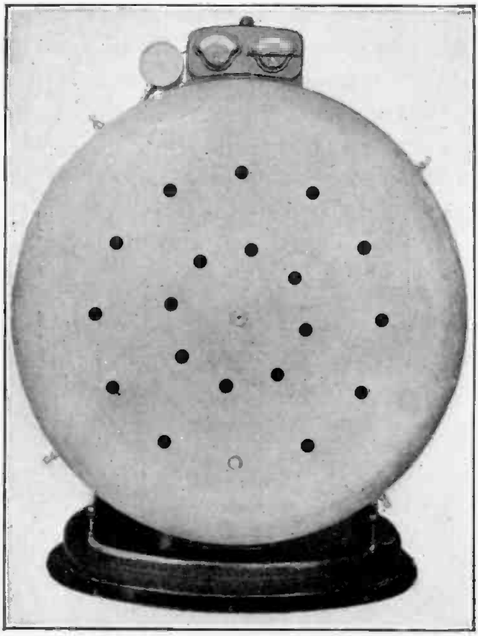


Fig. 5—Front of Gasoline Driven Generator for USS *Shenandoah*.

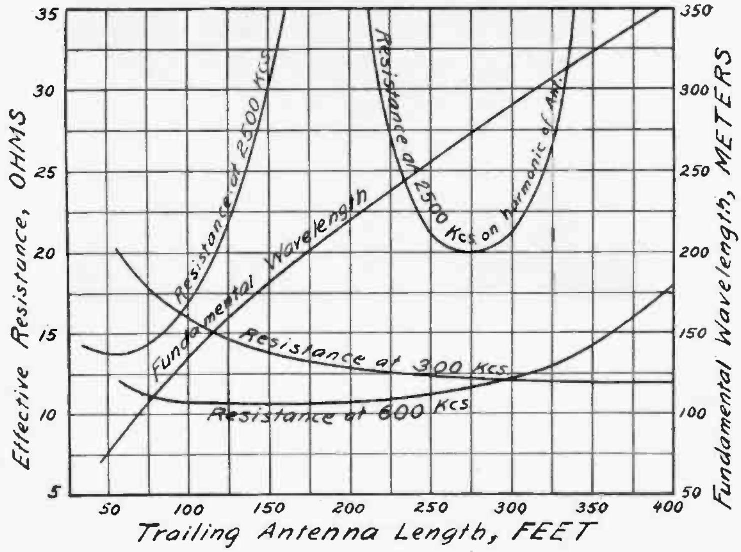


Fig. 6—Effective Resistance and Natural Wavelength Curves for Single Wire Trailing Antennas.

ated intermittently. Undue noise was avoided by enclosing the power supply equipment and batteries in a small separate compartment between the radio room and the control room.

When plans were made in 1923 to send the *Shenandoah* on an Arctic exploration flight, the preparations included design and construction by the Naval Research Laboratory of a long range radio transmitter, probably the largest and most powerful set ever built for aircraft. This transmitter is shown in Figs. 2 and 3. Notice the large antenna reel built into the lower

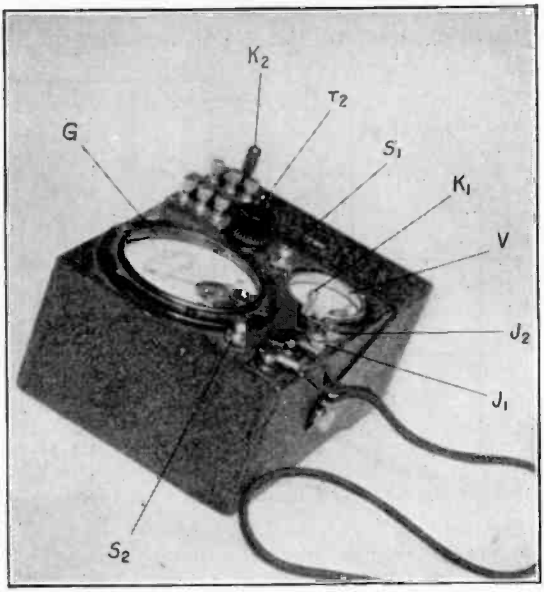


Fig. 7—Visual Signal Intensity Meter.

part to save space. ACW tone telegraphy with about two kilowatts antenna input was provided by eight 250-watt power amplifiers excited by two quarter-kilowatt master oscillators, at frequencies between 200 and 500 kc. The power supply for this transmitter is shown in Figs. 4 and 5; it consisted of a specially developed 15 H.P. gasoline-electric unit built by the Kinney Mfg. Co. of Boston, and delivered 5 K.V.A. at 220 volts, 660 cycles alternating current, as well as 2 kw. at 30 volts direct current for field excitation and battery charging. This unit was supported on a pneumatic cushion to reduce vibration

and noise. The weight of the transmitter unit shown was about 425 lbs. inclusive of tubes and antenna; the power supply unit weighed about the same. The normal telegraph range of this equipment was expected to be about 1500 miles in daylight. Because of abandonment of the Polar flight plans this powerful set was never installed in the ship, and subsequent developments in high-frequency equipment have made airship transmitters of this size and weight unnecessary for long distance communication.

The west coast cruise of the *Shenandoah* in the fall of 1924 gave an opportunity to test the possibilities of high-frequency aircraft equipment; despite the crude receivers of those days,

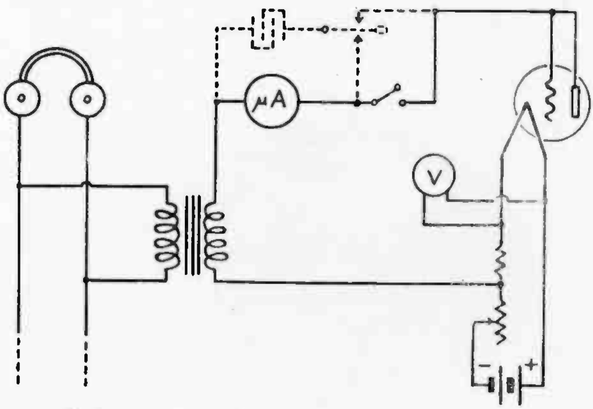


Fig. 8—Schematic Circuit Diagram of Visual Intensity Meter

two-way communication between the dirigible and the Naval Research Laboratory was accomplished night after night on the entire trip, the Laboratory employing a 54-meter transmitter with about 500 watts in the antenna, and the *Shenandoah* transmitting on 90 meters with 50 watts output. The USS *Canopus* reported instances of good night reception of the *Shenandoah's* signals at Guam while the airship was flying in the vicinity of Seattle, 5000 miles away.

Our only present rigid dirigible, the USS *Los Angeles*, is equipped with a German Telefunken intermediate-frequency transmitter of 200 watts antenna input, and a high-frequency 50-watt crystal-controlled transmitter operating on 3475 and 8012 kc.; either of these transmitters has a daylight range of approximately 500 miles. In addition, the *Los Angeles* is

equipped with a rotating coil radio compass, a German plug-in coil universal receiver, and a high-frequency receiver. Radio operating conditions on these dirigibles have been found very

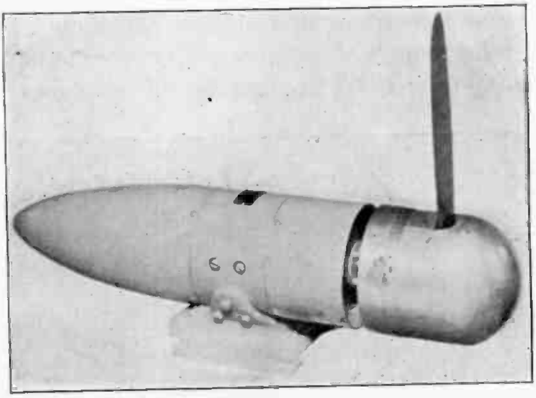


Fig. 9—R.C.A. Wind-Driven Radio Generator with Deslauriers Self-Regulating Propeller.

advantageous. In addition to the trailing-wire antenna employed, a short fixed antenna is provided which is especially valuable for communication with the ground crew in landing operations.

C. General Flight Conditions Affecting Radio

As previously mentioned, in view of the favorable radiation conditions in flight good results are usually attained by use of

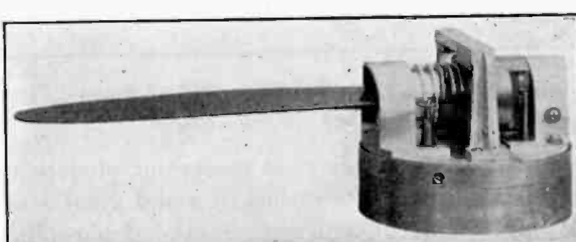


Fig. 10—Mechanism of Deslauriers Self-Regulating Propeller.

a single trailing wire antenna, against the metal structure and bonding of the plane as counterpoise; this gives a good effective height with relatively little absorption loss. An idea of the

effective resistance and the fundamental wavelength of such a trailing antenna is obtained by reference to Fig. 6, which is based upon average values observed on planes of moderately large size. As indicated by the 2500 kc. resistance curve, it is practicable and sometimes desirable at the higher frequencies to operate on harmonics of the antenna system; antenna lengths employed for intermediate frequencies on airplanes are some-

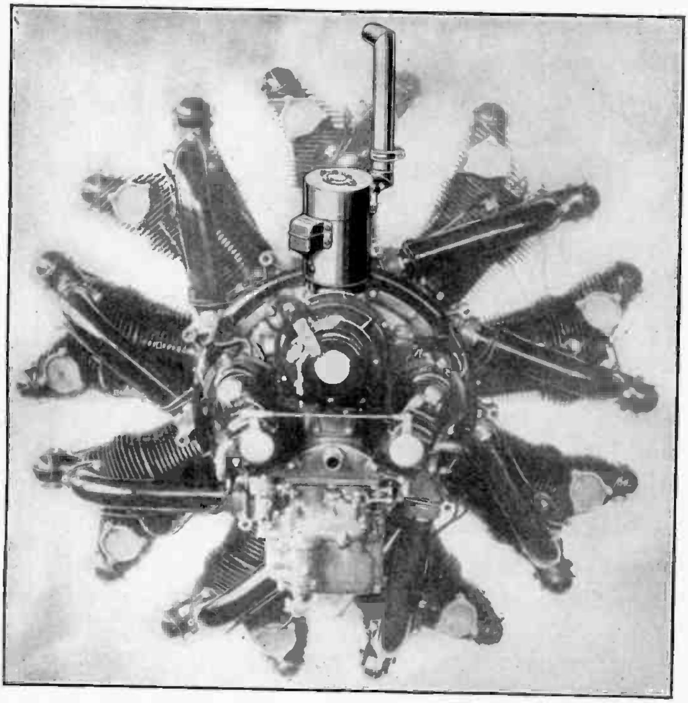


Fig. 11—Leece-Neville Generator Geared to Pratt and Whitney "Wasp" Engine.

times as much as 350 feet or even more, but modern tendency with efficient transmitters is rather to avoid great lengths, for reasons of safety and convenience. Stranded phosphor bronze or copperclad steel wire is generally employed, carrying a total weight of from two to five pounds at the end. To reduce the possibility of accidental loss and to make possible ready renewal of an antenna in flight, tubular antenna weights together with a large diameter fairlead to make them completely retractable are often used.

Space and weight restrictions imposed on all aircraft radio equipment are usually severe and can be met only by skilful design; all equipment should be readily accessible for inspection and maintenance and must be constructed to withstand continued vibration and landing shocks without breakage. Equipment is generally supported on cushions of sponge rubber or on spring suspensions, or is hung in place by a suspension of rubber exerciser cord, also known as "Bungee" cord. Too resilient a suspension, however, is unsuitable as it may allow the equipment to bounce around and suffer severe shocks from striking an adjacent object during a bumpy landing.

A precaution which is necessary for efficient radio operation and which is also desirable for general safety reasons is the proper bonding of aircraft. By this is meant a thorough electrical interconnection of all metallic parts of the plane or airship,

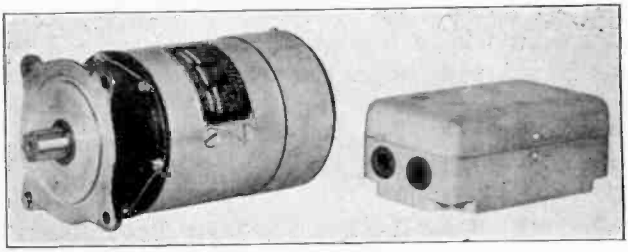


Fig. 12—Eclipse Engine Mounting Generator with Voltage Regulator.

with permissible exception only of such isolated parts as actually are well-insulated from the main metal structure. Bonding is effected by means of copper straps or pigtails, with particular attention to clean and durable connections. The purpose of bonding is three-fold: First, it reduces fire hazard by preventing sparking between adjacent metallic parts. In the absence of bonding such sparks may occur as the result of charges of atmospheric electricity or from voltages induced by radio transmission. Obviously, especial care must be exercised to bond all fuel tanks and feed pipes with adjacent metal work; on hydrogen-filled dirigibles, bonding of all metal parts in the vicinity of the gas cells or envelope is a safety precaution of the greatest importance. A second advantage of bonding is the resulting increase of effective counterpoise area for radio transmission, and reduction of the radio-frequency resistance.

Thirdly, absence of bonding may cause many electrical disturbances in radio reception, resulting from intermittent slapping or rubbing together of separate conductors in the field of the antenna-counterpoise system. To avoid such noises par-

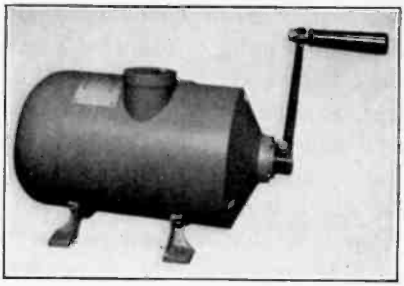


Fig. 13—Evershed's Hand-Driven Radio Generator, with Automatic Contactor.

ticular attention should be paid to control wires; it is modern practice to run such cables through sheaves and guides which are either well-grounded or well-insulated and to cover one or both cables with insulating sleeves at points where they cross and may slap together in flight.

D. Aircraft Radio Receiver Problems

There are many conditions adversely affecting radio reception in flight; these are only recently being overcome in a

Fig. 14—Code Disk Arrangement in Frost's Automatic Contactor.

satisfactory degree, by specialized design and installation precautions. One of the worst obstacles is the great noise produced by the motor, usually accompanied by noise from the propeller and whistling of exposed wires. These noises, which are naturally more pronounced in open planes, can be partly

excluded by well-fitting radio helmets with pads or rubber cups surrounding the ear pieces; nevertheless, a very strong signal is generally required in order to be heard in flight. Radio disturbances produced by the motor spark plugs and leads often interfere seriously with reception and can be entirely avoided only by careful and systematic electrical shielding and bonding of the entire ignition system. In studying the strengths of signals and ignition disturbances encountered with various receivers, the Naval Research Laboratory in 1926 developed a small portable visual intensity meter, shown in Fig. 7. As seen in

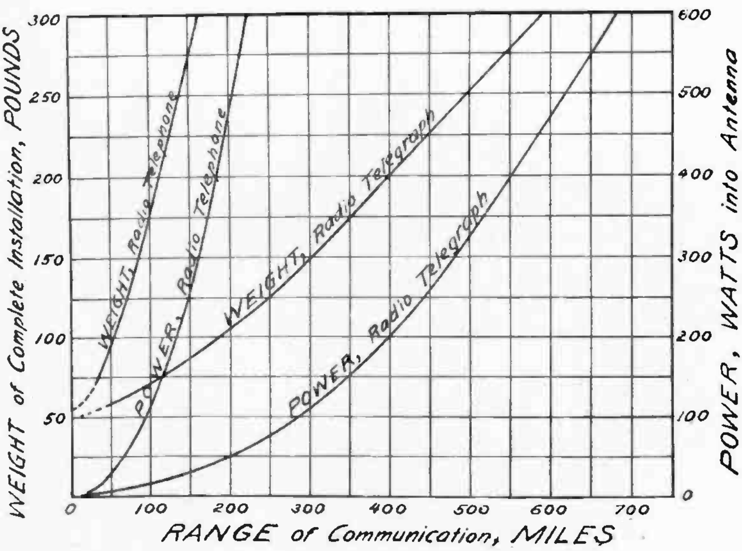


Fig. 15—Weight-Power-Range Curves for Typical Aircraft Radio Installations for Frequencies between 250 and 1000 kc.

the schematic diagram of Fig. 8, the signal voltage is measured receiving tube employed as rectifier and coupled across the telephones by means of a small step-down transformer. In dotted lines is shown an integrating attachment consisting of a 4 μf high-grade paper condenser with a charge and discharge key; telegraph signals or other weak or irregular disturbances may be averaged by charging this condenser through the rectifying tube during a given length of time and then reading the discharge kick through the microammeter. With the aid of this intensity meter it has been found that signal strengths giving

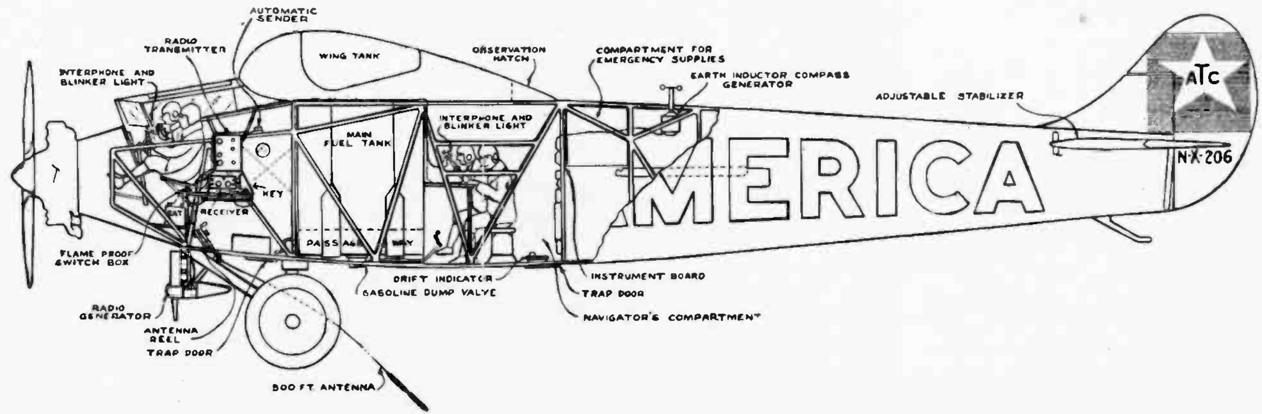


Fig. 16—Interior Arrangement of Byrd's Airplane *America*.

approximately 1.5 to 2.0 volts r.m.s. across the headphones are ordinarily required for satisfactory reception in flight.

Serious microphone noises may be set up by vibration of tube elements or condenser plates, and often require special design and suspension. Particular non-microphonic tubes with rigid elements have recently been developed for aircraft use. Audio tuning by peaked transformers or trap circuits is at times of value in reducing disturbances in telegraph reception, but obviously is unsuitable for radiotelephony. Series condensers in the antenna or ground connection should be

Fig. 17—Forward Portion of Airplane *America*.

avoided or shunted by a choke or resistance leak in order to prevent sparking from accumulated static charges. Often at least the plate batteries are self-contained in the receiver to save space; recently both Naval and commercial aircraft receivers have been successfully employed without batteries, by deriving their voltages from the wind-driven generator which furnishes power to the transmitter.

E. Transmitter Design Considerations

Aircraft radio transmitters must be of very compact, yet durable and accessible construction, and as in the case of the receiving equipment, wiring connections should have a certain resilience and be mechanically anchored so as not to loosen up

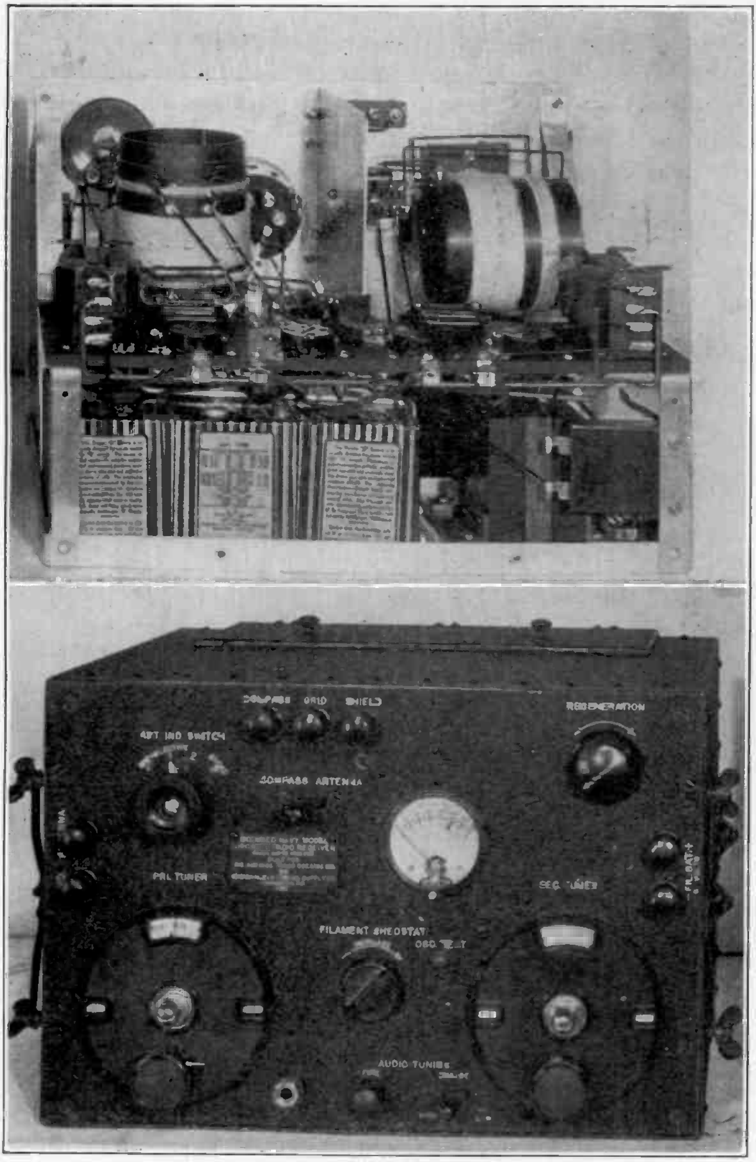


Fig. 18—Radio Receiver Used on Byrd's Transatlantic Flight.

or break at soldered joints under continued vibration. Intricate adjustments should generally be avoided in order to enable effective operation by untrained personnel. High-voltage circuits should be well protected against accidental short circuits under vibration, and safety precautions should be taken to minimize danger to the operator while doing any necessary

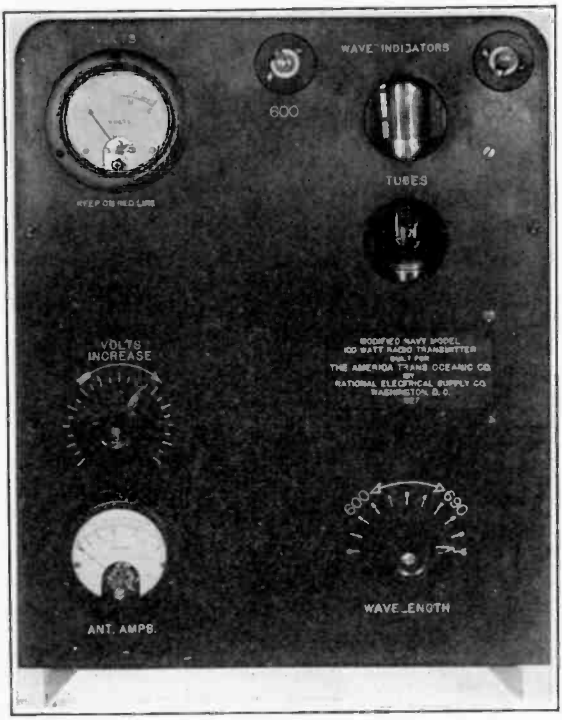


Fig. 19—150-Watt Transmitter of Airplane *America*, Front View.

work on the transmitter under confined flight conditions. As a rule, it is especially desirable in closed planes to guard against danger of fire by encasing all sparking switch contacts in flameproof boxes, to prevent ignition of any gasoline fumes which may be present. As an added precaution against fire, insulating materials throughout should be of highest grade and properly employed, with particular attention to avoid chafing under vibration. In radiotelephony some disturbances in transmission may be encountered from flight noises, but these have been

considerably minimized by special anti-noise microphones which are sensitive to voice but exclude or balance out most extraneous sounds.

The power supply for the transmitter radio generator may be derived directly from the airplane motor by gearing, or indirectly by fan drive in the airstream, or from a storage

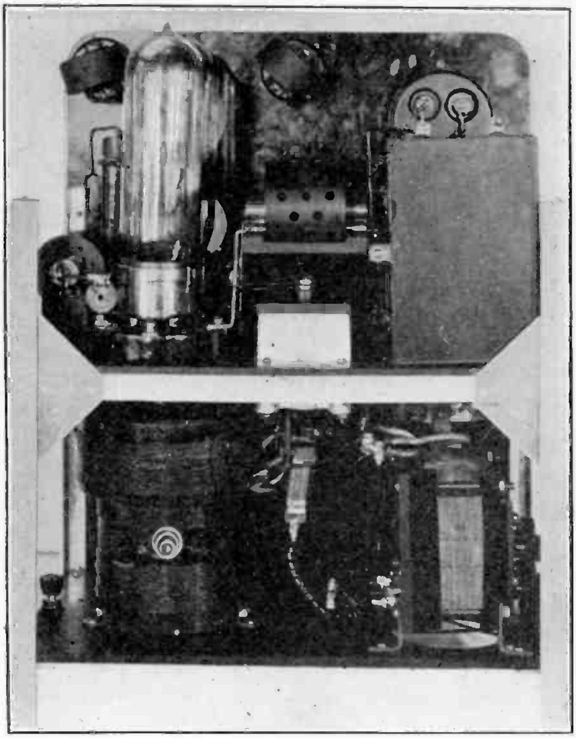


Fig. 20—Rear View of *America* Transmitter.

battery through a suitable dynamotor. The latter method will readily furnish full power on the ground or water as well as in flight, but permits operation in flight for a limited time only, unless the battery is kept charged by another generator, such as has been done on many Army installations. The wind-driven generator with self-regulating fan gives the most flexible installation and will furnish power as long as the plane is in flight; if suitably installed in the propeller slipstream, the wind-driven

generator can also be made to turn up on the ground, for testing or for emergency communication. Fig. 9 shows a streamlined radio generator of several hundred watts output, supplying filament and plate voltages, and driven by a self-regulating air propeller. In Fig. 10 is shown the centrifugal governing mechanism which regulates the pitch of the counterbalanced single blade to keep the speed of rotation constant. Fig. 11 shows a 12-volt, 15-ampere generator mounted on an air-cooled engine; notice the ventilating stack for cooling the generator. Fig. 12 shows a somewhat similar generator with its mounting flange, and the box containing a vibrating voltage regulator as well

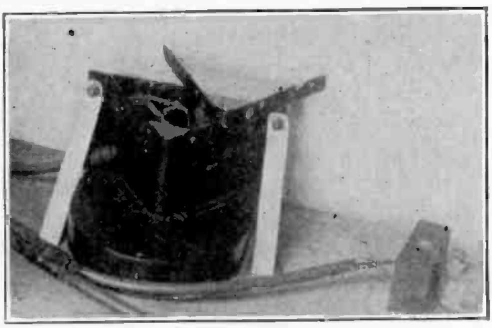


Fig. 21—Wind-Driven Call Disk Installed in Airplane *America*.

as a battery cut-out. Such generators, for radio purposes, are provided with separate commutators for plate and filament voltages and are now manufactured by several concerns.

A type of current supply especially suitable for emergency use is the hand-driven radio generator shown in Fig. 13. This device, of British make, furnishes up to 50 watts of combined electrical energy for plate and filament supply; it has been found that one man is not able to exceed this power for any length of time, and in view of this fact, such hand-driven generators lend themselves especially to high-frequency emergency transmitters, which may despite their low power reach out over great distances. Fig. 14 shows an automatic contactor incorporated in some models of the hand generator, enabling automatic transmission of any chosen letter combination as the generator is cranked.

In another part of this paper is described a high-frequency transmitter which effectively uses dry batteries as power source.

F. Comparison of Radiotelephony with Radiotelegraphy

Because of its convenience and in view of personnel limitations it is likely that radiotelephony will continue to be employed extensively for many classes of aircraft communication, up to distances of 100 miles or more. Where accuracy of communication, simplicity of equipment, or distance range without

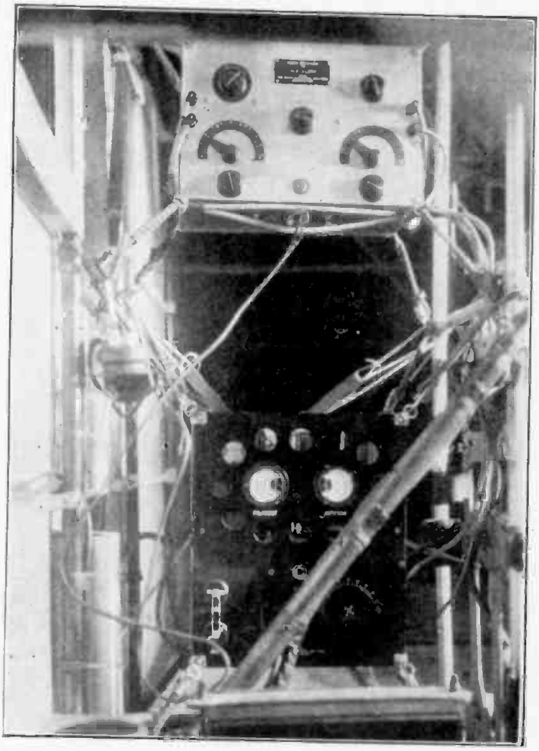


Fig. 22—Radio Installation by Allen D. Cardwell Co., in Airplane *Old Glory*, Front View.

excessive power are requirements, however, radiotelegraphy offers advantages, provided suitable operating personnel is available. In Fig. 15 are shown curves, based on average American and foreign practice, which compare average intermediate frequency communication range with antenna power and total installation weight, for radiotelegraph and radiotelephone equipment. Practice has shown that for a given antenna power and under average conditions, well-modulated radiotelephony will

carry approximately one-third the distance obtainable with radiotelegraphy, while the weight for a telephonic installation is 15 to 20 per cent greater and correspondingly more complicated. Under adverse conditions of communication and with insufficient ignition shielding, radiotelephony is impaired to a greater extent

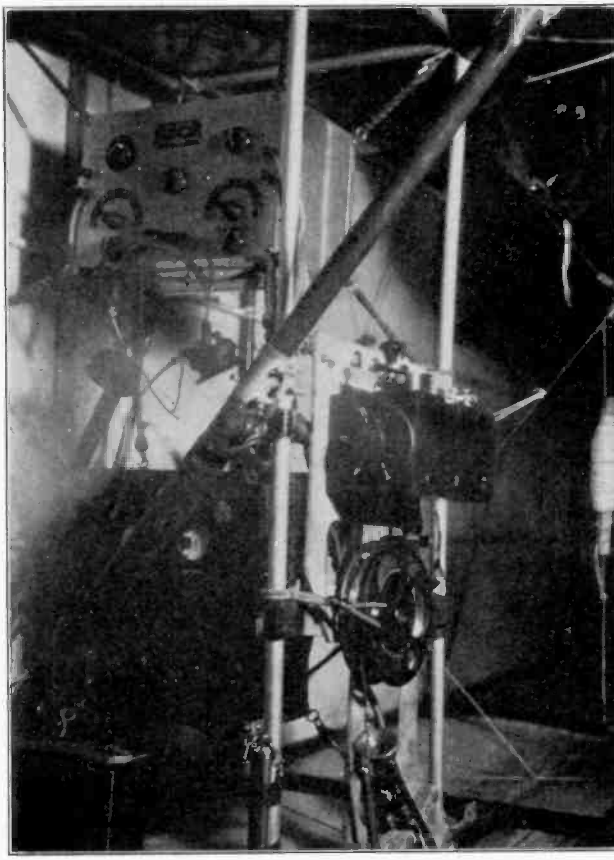


Fig. 23—Another View of *Old Glory* Installation.

than telegraphy, while under especially favorable conditions a better ratio may be obtainable than shown by the curve. As a rule, radiotelephone equipment is arranged to provide radiotelegraph transmission at will by a simple switch-over arrangement. It must be borne in mind, however, that equipment designed solely for radiotelegraphy is not only much simpler in

construction, but the tubes and circuits may be safely loaded to a greater extent in view of the intermittent keying in place of a continuous carrier and modulation current.

G. Some Expeditionary Installations

Long-range telegraphic equipment in its simplest form and of lightest weight is required for many expeditionary and long-distance flights. Where such flights are over long stretches of water an intermediate frequency without skip-distance and near the ship calling wave has obvious advantages. A typical installation of this sort was carried on Commander Byrd's flight across the Atlantic, installed in his airplane *America* as shown in Fig. 16. The equipment was patterned after installations which have proved their value on Naval scouting planes,

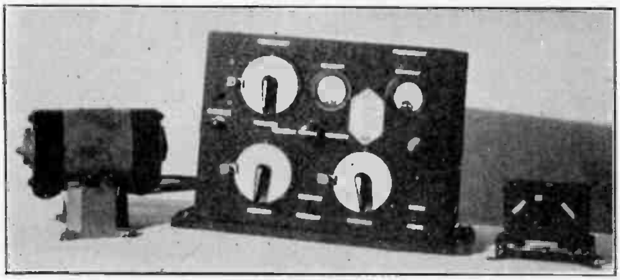


Fig. 24—Combined 600- and 45-Meter R.C.A. Transmitter Built for Airplane *American Legion*.

but was modified in several respects for the sake of lightness, simplicity, and dependability, with the results that it functioned without failure during the entire forty-one hours that the plane was in the air. The wind-driven radio generator shown in Fig. 17 was a standard Navy type delivering 500 watts at 200 volts, 400 cycles, with the fan adjusted to 4000 r.p.m. Its location under the fuselage and near the landing wheels was prompted by necessity but exposed the fan to possible danger from flying stones and mud particles during take-off, and from swinging antenna weights while reeling in. Fig. 18 shows the receiver with self-contained plate battery which employed four tubes, namely, one stage of tuned neutralized r.f. amplification followed by a regenerative detector and two stages of audio amplification; a tuning range from 200 to 800 kc. was provided. Audio tuning of variable pitch could be switched across the

detector output if desired, and microphonic tube noises were reduced by acoustic damping with sponge rubber, sound shielding with lead foil, and damped flexible tube supports. Fig. 19 shows the front panel of the transmitter, which employed two 50-watt tubes, type UX-211 and delivered approximately 150 watts to the antenna. A full-wave self-rectifying circuit was employed with a transformer giving a plate voltage of about 1500 r.m.s. on either side of center tap. An antenna variometer enabled tuning to either a 690-meter working wave or a 600-

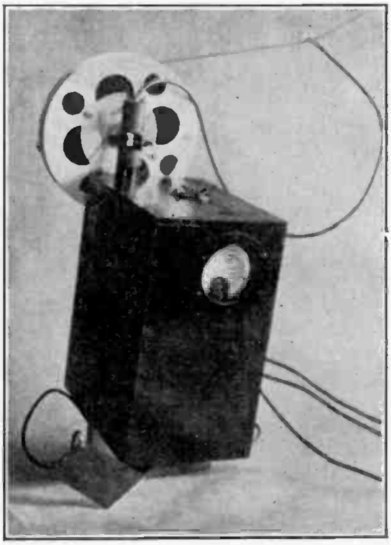


Fig. 25—Waterproof Self-Contained Emergency Spark Coil Transmitter.

meter calling and emergency wave, resonance to either being indicated by one of two small fixed wavemeter circuits with glow lamps, located in the upper portion of the panel. Fig. 20 shows the rear of this transmitter with the wavemeter circuits. In Fig. 21 is seen an innovation which proved of great value on this flight, namely, a wind-driven automatic code disk which continuously repeated the *America's* call letters WTW at times when the operator was engaged with non-radio duties; by this means stations and ships within range were enabled to keep track of and take bearings on the *America's* signals at all times and were kept on the alert for any messages and communications.

Fig. 22 shows an installation somewhat similar to Byrd's in the airplane *Old Glory*, which in the summer of 1927 met disaster on an attempted New York to Rome flight. The installation is more fully shown in Fig. 23; the transmitting key is atop the flame-proof switch box, and under it is the antenna reel with fairlead and tubular antenna weights.

A totally different transmitter suitable for long-distance flights is shown in Fig. 24; this set, developed by the Westinghouse Company for the Radio Corporation gave excellent re-

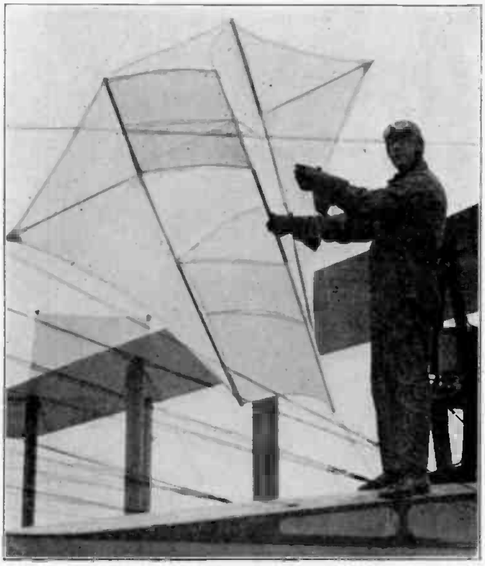


Fig. 26—Navy Emergency Radio Kite.

sults on its test flights in Commander Davis' and Lieut. Wooster's ill-fated *American Legion*. The transmitter is operated from a storage battery and dynamotor and provides for approximately fifty watts CW output on either 45 meters or 600 meters; the 45-meter wave is crystal-controlled, while in the 600-meter position the transmitter is self-oscillating. A dependable transmitter of this type in the hands of a competent operator will give effective long-distance communication on high frequency, while providing for contact with commercial ship and shore stations on the 600-meter wave. Another advantage of this wavelength combination is the possibility of

bridging with the 600-meter transmission any fading or skip zone likely to arise at moderate distances with the short wave.

H. Emergency Radio Equipment

For possible use in case of a forced landing, a completely waterproof and self-contained emergency transmitter was de-

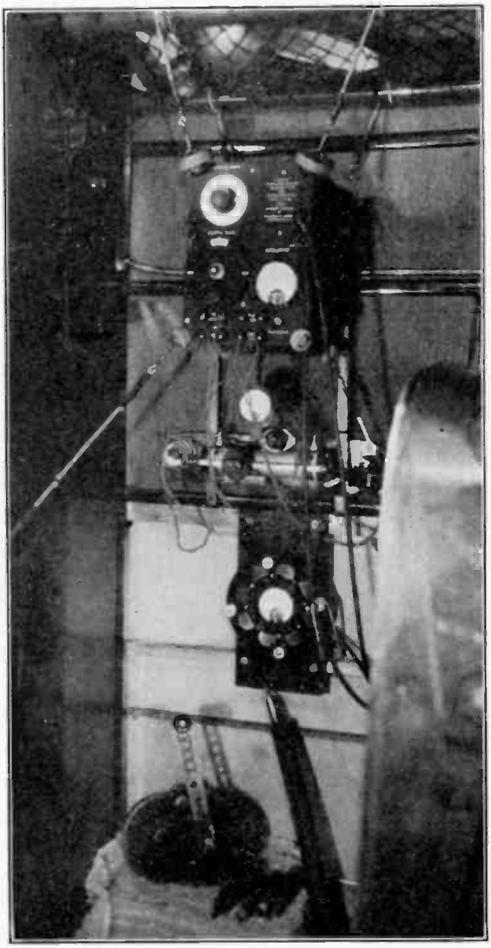


Fig. 27—High-Frequency Radio Transmitter Installation in Fokker Monoplane, Wilkins-Detroit Arctic Expedition, 1926.

vised for Byrd's *America*, and so constructed that it could be operated from one of the inflated life rafts if required; such

transmitters were also carried by several other transatlantic flight contestants. This set, shown in Fig. 25, employed a spark coil operated from internally contained flashlight batteries which sufficed for several hours' telegraph operation; projecting waterproof leads made possible external connection to any other available battery. The small ground-plate shown was to be dropped into the water, while a 300-foot length of wire held aloft by a kite served as antenna. A radiation meter mounted behind a waterproof window indicated antenna current and resonance; tight inductive coupling with a fixed primary cir-

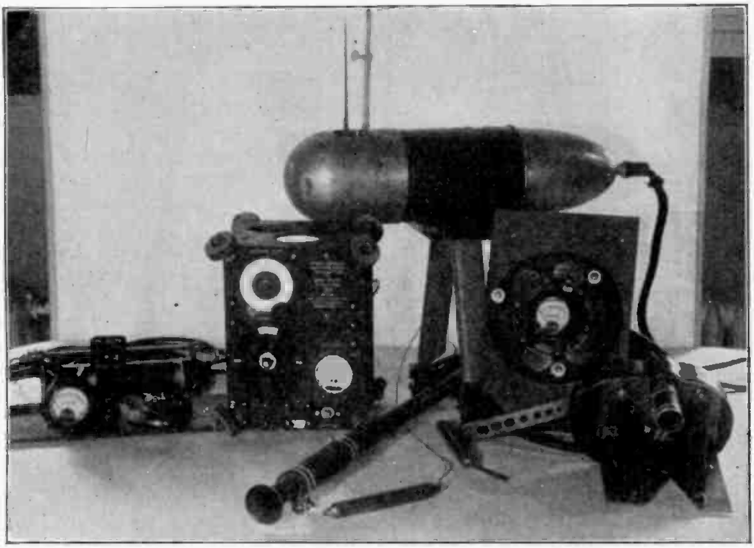


Fig. 28—Component Parts of Radio Installation Used by Byrd on Flight over North Pole.

cuit tuned to 600 meters was employed. In tests, fair signals were still obtained from this transmitter at 25 miles distance. A standard Navy kite for carrying aloft an emergency antenna is shown in Fig. 26; such kites are provided in two sizes of 6 and $7\frac{1}{2}$ feet height, for strong and light winds, respectively.

Naval flying boats on the water employ for radio communication either a kite antenna or a fixed antenna supported by the wings and the tail structure. Power for the main transmitter may be obtained from a wind-driven generator in the slip stream of an operating propeller; hand-driven generators in conjunction with high-frequency transmitters have also been employed

for emergency operation, but in several instances have proved objectionable due to fatigue of personnel and the required departure from the plane's regular working frequency.

Some foreign airplanes are provided with balloons in place of antenna kites for emergency operation, and carry small bottles of compressed hydrogen for inflation purposes. Small

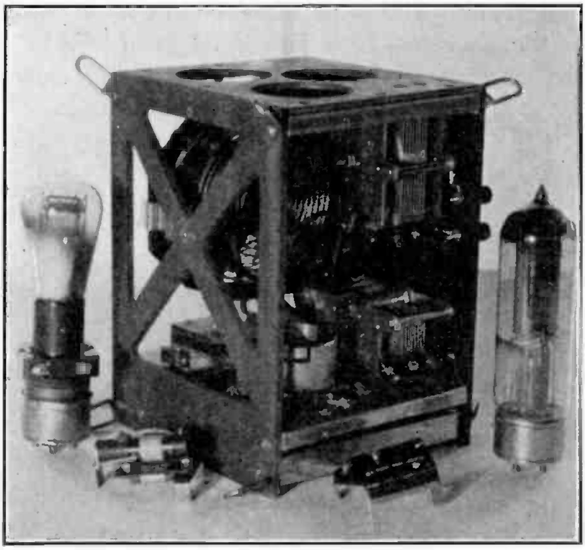


Fig. 29—Rear View of Byrd's High-Frequency Transmitter.

gasoline engines for emergency power have also been used to some extent, and are being experimented with in this country.

I. High Frequencies in Aircraft Communications

Great distance possibilities in low-power transmission from airplanes were established by the Naval Research Laboratory in flight tests during 1924, and with the cooperation of a large number of radio amateurs were confirmed during the summer of 1925, when a number of distance tests were made in flight with a simple crystal-controlled telegraph transmitter operating on waves as short as 22 meters; the extremely thin crystals operated with an impressed plate voltage of about 250 volts, and gave an antenna input from one to two watts with two 201-A type receiving tubes connected in parallel. With this low power, 25-meter flight tests conducted near mid-day were

heard as far as Unity, Saskatchewan, a distance of 1800 miles, and were reported also by a number of other stations beyond a thousand mile radius; this wave, however, showed a decided skip zone inside of 500 miles. A 40-meter wave, employed alternately with the higher frequency, showed less than 800 miles range but had no skip zone, although at close range fading was often pronounced and reception especially poor when the plane flew at low altitude. Reception of high frequencies in flight was found to be greatly hampered by ignition disturbance as well as vibration detuning and microphonic

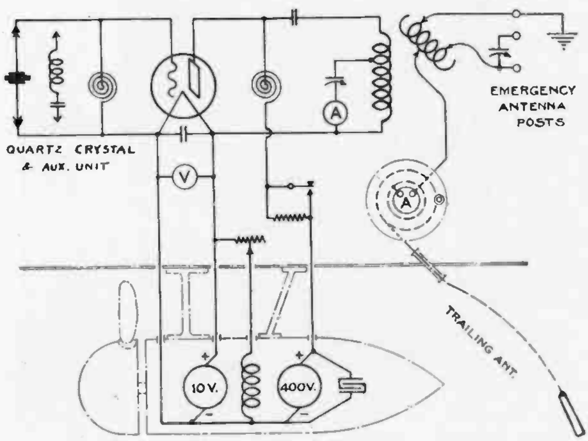


Fig. 30—Schematic Diagram of Crystal-Controlled High-Frequency Aircraft Transmitter.

noises, but has since been accomplished effectively with suitably installed receivers of improved design.

When Captain George H. Wilkins conferred with the Navy in December, 1925, regarding suitable airplane equipment for his proposed North Pole flight to be attempted the following spring, the value of high frequencies for his purpose became apparent, and at his request a suitable airplane transmitter of very low weight was designed and constructed by the writer. This set, installed in Wilkins' single-motored Fokker plane, is shown in Fig. 27; an antenna input between 10 and 20 watts was obtained from a 50-watt Western Electric tube, with 400 volts on the plate, at crystal frequencies of approximately 5000 and 7000 kc. At Commander Byrd's request identical apparatus was constructed for his North Pole flight; this is shown in Fig. 28. Notice at the right the improvised hand

gearing which was carried in the plane to replace the wind propeller in case of a forced landing. Fortunately Byrd did not need to employ this gearing on his flight; the few messages sent back to his base ship at Spitzbergen during the Polar flight

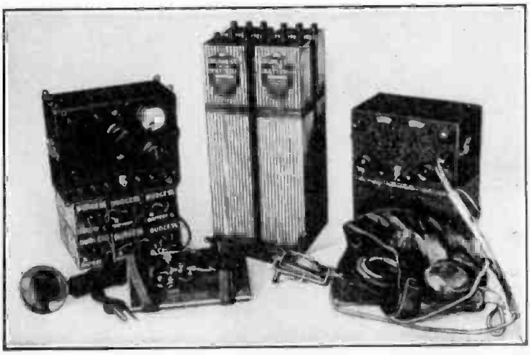


Fig. 31—Burgess Experimental Aircraft Set.

were received with good strength, but badly garbled by continuous spark interference from a schooner anchored nearby, carrying a flock of newspaper correspondents. More use was made of his radio equipment by Wilkins, who regularly communicated

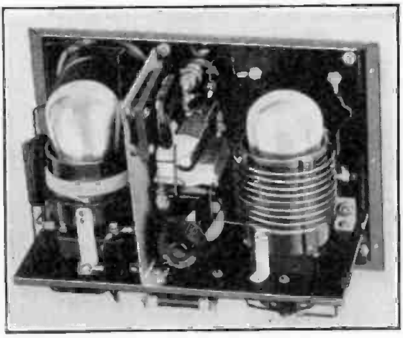


Fig. 32—Rear View of Interior, Burgess Airplane Transmitter.

over the 500-mile distance fron Point Barrow to Fairbanks, Alaska, even when turning the emergency gear from the ground. After two seasons' flight use, Wilkins in 1927 was finally forced to abandon this set on the polar ice with his damaged plane; after notifying the world of his forced landing, he and his pilot

Eielson had a month's struggle back to the mainland. He left behind with the set an Evershed hand generator which he had employed with good success. Fig. 29 shows the back of the Byrd-Wilkins set, with spare crystal and emergency

Fig. 33—Burgess Radio Equipment Installed in Travel Airplane.

self-oscillation unit, as well as emergency adapter and $7\frac{1}{2}$-watt tube for easier cranking in hand operation. The schematic diagram of the set is shown in Fig. 30; for ground operation, in place of the quarter or three-quarter wave trailing wire a simple fixed antenna could be improvised and tuned by means of

a variable condenser connected in series or parallel with the antenna and counterpoise.

In view of excellent results obtained in point-to-point communication by Wilkins and others with portable high-frequency, battery-operated transmitting equipment of very low power, the Burgess Battery Company undertook a series of flight tests which resulted in the development of some extremely compact experimental aircraft radio equipment of interesting perform-

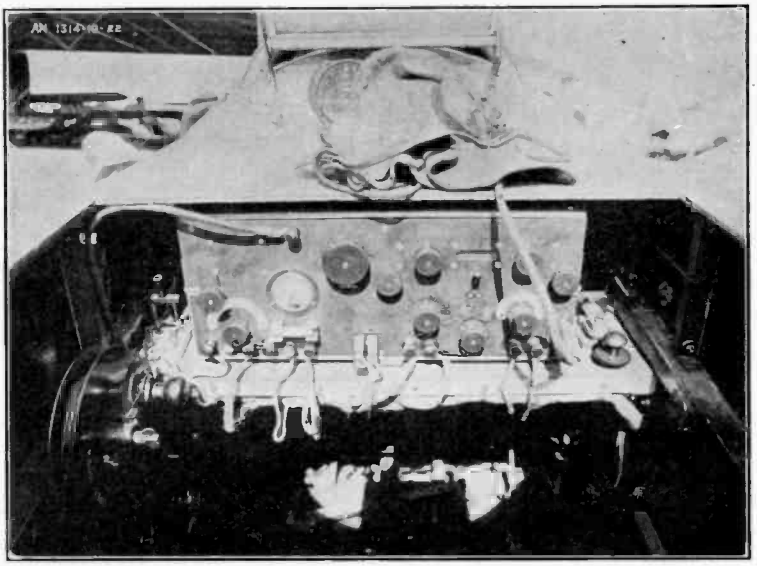


Fig. 34—Installation of Navy Type SE-1375 Transmitter-Receiver in Two-Seater Observation Plane.

ance, shown in Fig. 31. Fig. 32 is an inside view of the little transmitter which employs one 201-A tube, shown at the left, as master oscillator, and a similar tube as balanced power amplifier. With 350 volts on the amplifier and 180 volts on the master oscillator plate, an antenna input of about 4 watts is reported; the master oscillator may be speech modulated by means of an absorption loop shown just beneath the white inductance winding. Installed in a Travel Air plane as shown in Fig. 33, experimental two-way communication with amateurs was accomplished on 79 meters up to 500 miles, and on 40 meters the plane's signals were reported up to a distance of 725 miles. Further contemplated tests with equipment of this

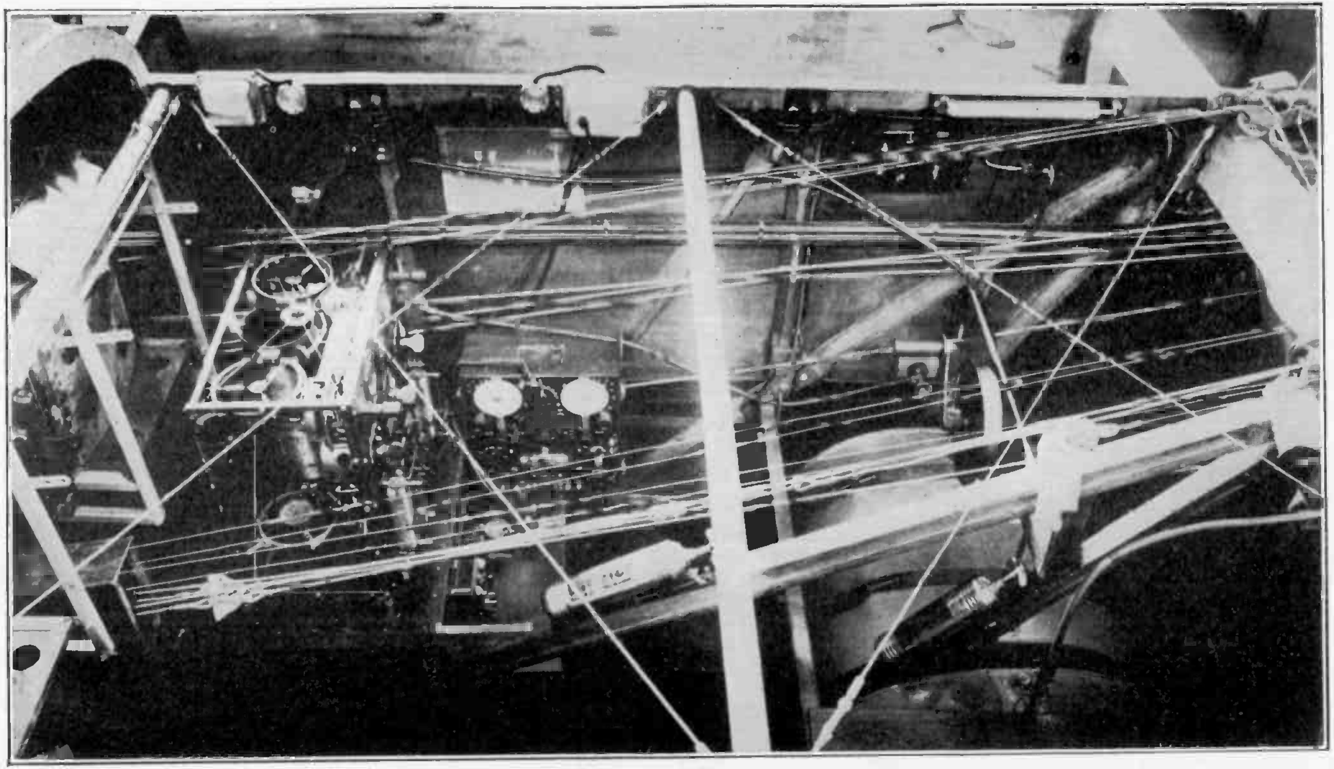


Fig. 35—War-Time Installation in Navy Flying Boat.

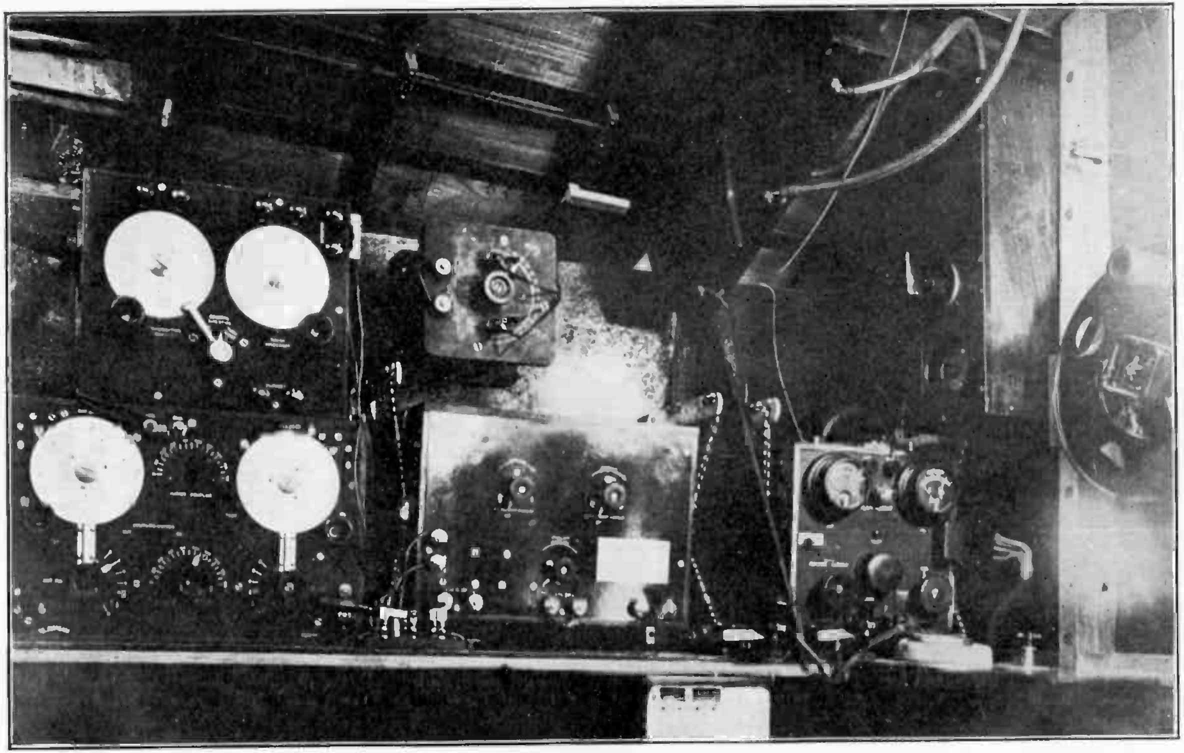


Fig. 36—Radio Installation in Nc-1 Flying Boat.

type are looked forward to with great interest to determine its possibilities in certain commercial applications. There is no question that for expeditionary purposes and uses requiring extreme portability, high frequencies offer great possibilities which in aircraft communication so far have only just begun to be realized. When the *Spirit of Dallas* went into a tail spin and disappeared into the Pacific Ocean last year, her SOS, transmitted on a 33-meter wave with a simple 50-watt set, was heard in New York City, and beyond as far as Italy. Ex-

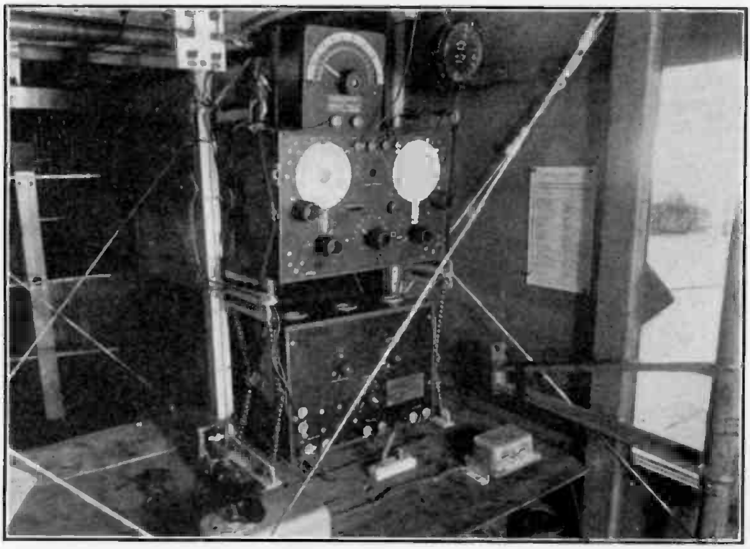


Fig. 37—Radio Compass Equipment in H-16 Type Flying Boat.

tremely interesting results in high-frequency airplane experiments have also been obtained in Germany.[1]

J. Naval Airplane Radio Installations

The early developments and extensive applications of Aircraft Radio in our Naval service are described in articles by T. Johnson, Jr.[2] Under the pressure of the war there was rapid and spectacular development; subsequently, there have been a no less important refinement, steady growth of application, and experimental research, which have resulted not only in in-

[1] Plendl, H., "Die Anwendung Kurzer Wellen im Verkehr mit Flugzeugen." *Zeitsch. fuer Tech. Physik*, pp. 277-282, No. 7, 1927.
[2] Proc. I.R.E., 20, 1, 2; February and April, 1920.

creased dependability and performance of our aircraft radio equipment for military uses, but have taught our manufacturers many valuable lessons and laid the foundation to development of equipment meeting the distinct communication needs of our new civil air commerce.

Fig. 34 shows a simple and efficient self-rectifying telegraph transmitter and receiver model, installed for test in a post-war two-seater observation plane; with four 5-watt tubes, a tele-

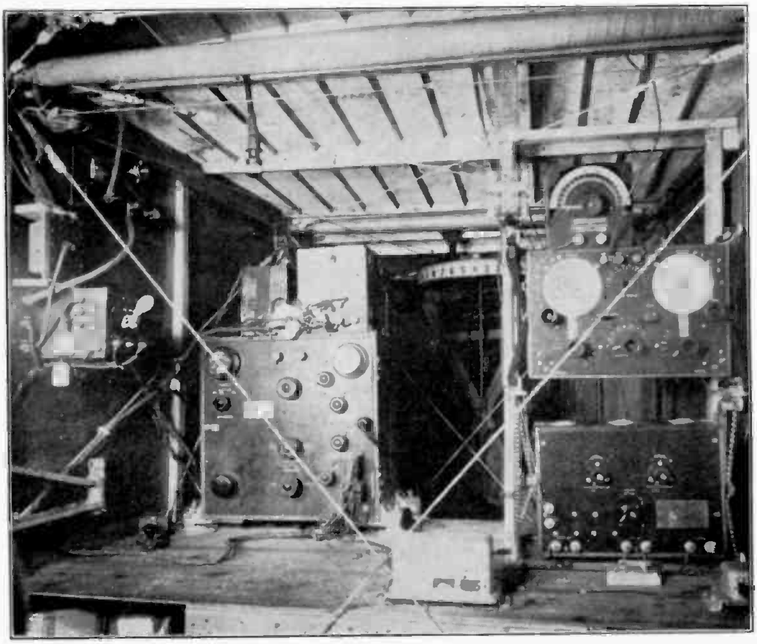


Fig. 38—Complete Installation in H-16 Boat.

graph range of about 125 miles was normally obtained. In Fig. 35 is seen again a standard war-time installation in an F-5-L flying boat. Fig. 36 shows the installation in one of the NC planes. At the left are shown the compass receiving gear and tuner, followed by a six-tube detector-amplifier. A large antenna switch is attached to the upper bulkhead, while on the end partition is seen the transmitter variometer, with the trailing wire antenna reel alongside. A CG-1104-A, 5-watt auxiliary tube transmitter for voice or telegraph is shown on the table at the right, with the jack box for the interphone

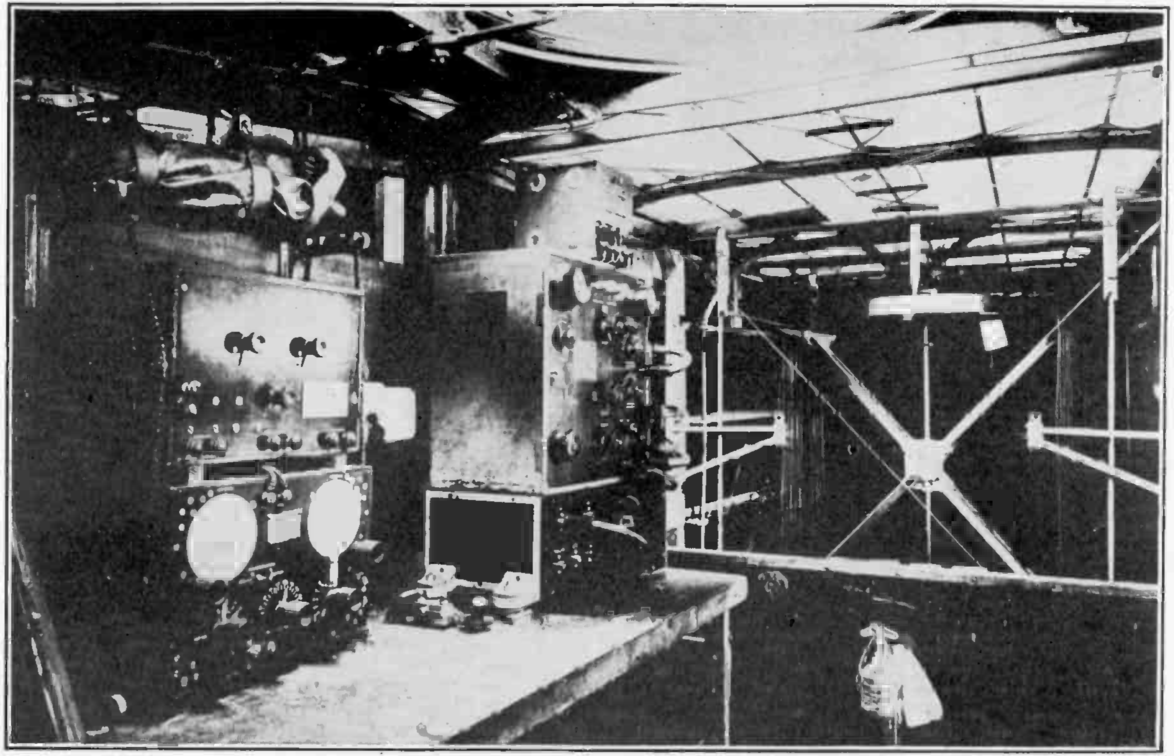


Fig. 39—Radio Equipment in PN-7 Flying Boat.

radio compass coil was mounted in the extreme after portion of the hull, on the other side of the bulkhead carrying the antenna reel, and was observable through a small window; the cord for rotating the coil is seen with one of its pulleys just above the antenna reel. The valuable radio results obtained on the trans-atlantic flight by the NC-4 are well-known, and gave rise to much interest in the possibilities of radio direction finders aboard large aircraft.

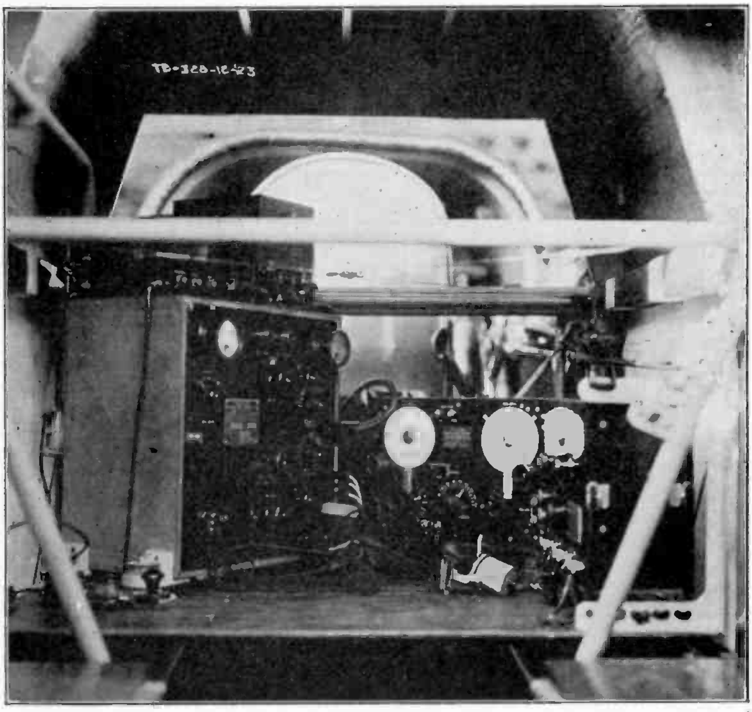


Fig. 40—Radio Installation in DT-2 Torpedo Plane.

To test and demonstrate further the possibilities of radio direction finders, a flying boat of the H-16 type was fitted with a radio compass installation as shown in Figs. 37 and 38; early in 1920 it was given the mission to locate the battleship *Ohio* which was 100 miles out at sea in an unknown direction. Immediately upon taking off from Hampton Roads, the plane obtained definite directional bearings on the *Ohio's* transmission, and by following these bearings, inside of an hour and a

below. A 500-watt spark transmitter enclosed in a stream lined case with its generator was mounted outside, above the hull. The half passed directly over the masts of the ship, despite very poor conditions of visibility. Fig. 37 shows the radio compass equipment; note especially the shock proof receiver suspension on rubber cord. In Fig. 38 is shown also the combined telephone and telegraph 50-watt transmitter type SE-1390. Note also the pulley arrangement for rotating the compass loop.

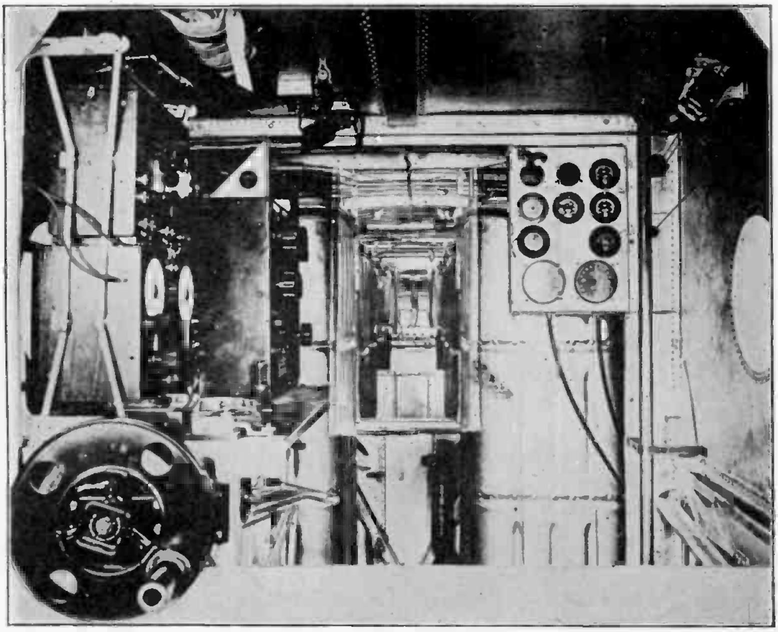


Fig. 41—Radio Installation in Commander Rogers' PN-9 Flying Boat.

A more refined service installation is shown in Fig. 39, which shows the after portion in a PN-7 flying boat; this photograph was taken in 1924 and shows an improved type of compass coil with a series-parallel switch in its center. Note the transposed wiring along the top between compass coil and receiver. Fig. 40 shows a service radio installation in a Torpedo plane where space is somewhat more confined than in flying boats. In Fig. 41 is seen the neat radio installation in the PN-9 metal hull flying boat in which Commander Rogers attempted an Hawaiian flight in 1925. Notice especially the large fuel tanks on either side of the narrow passage-way leading forward, and

the all-metal construction, which prevented use of a radio compass coil on account of shielding.

An elaborate installation of Naval intermediate and high-frequency equipment is shown in Fig. 42, installed in the Sikorsky S-37. Of especial interest is the retractible swinging generator mount at the left, which enables withdrawal of the generator from the airstream for inspection purposes and to reduce wind resistance when radio is not employed. Uppermost on

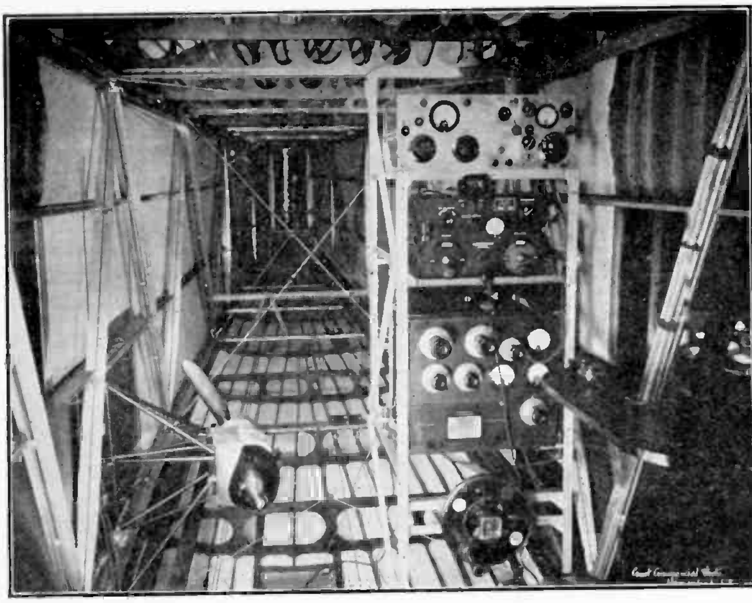


Fig. 42—Radio Installation in Sikorsky S-37 for Fonck's Transatlantic Flight, 1927.

the apparatus rack is shown a high-frequency 10-watt transmitter-receiver built for emergency communication. Below this is a standard intermediate-frequency aircraft receiver, and at the bottom is mounted a standard aircraft transmitter; this transmitter develops about 150 watts into the trailing wire antenna, at intermediate frequencies, employing 400-cycle, self-rectified ACW. The transatlantic flight proposed in this plane last year was indefinitely postponed, so that no opportunity was had thoroughly to test this attractive installation.

K. Directional Radio Devices for Aircraft

The possible applications of directional radio devices to aerial navigation may be broadly classified into three different groups, namely, directional radio receivers on aircraft, directional receiving stations on ground, and directional transmitters on ground.

Radio direction finders installed on aircraft, have in many instances in the past been employed with excellent success and have obvious advantages on large planes operating and navigating independently of extensive ground assistance, as well as

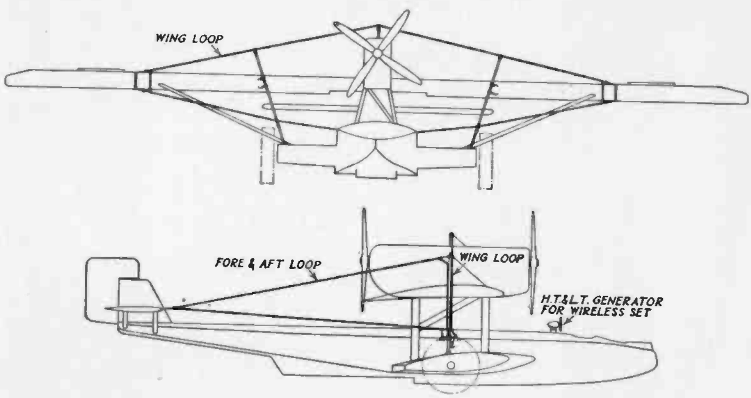
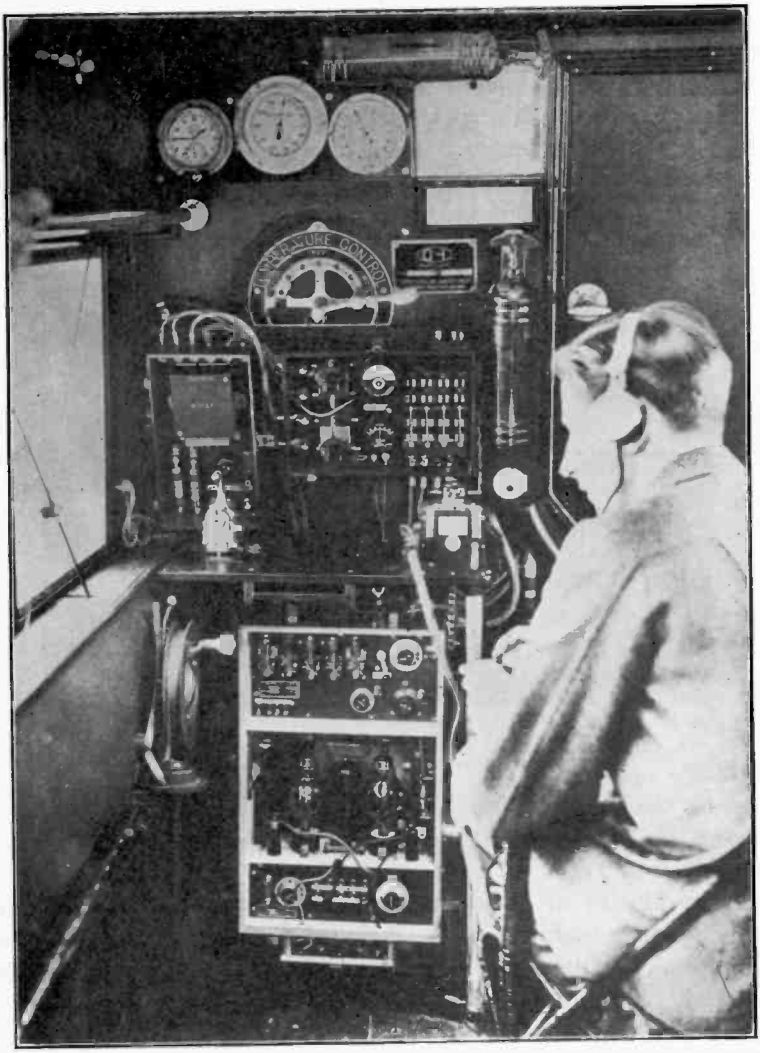


Fig. 43—Arrangement of Fixed Compass Loops on Dornier Flying Boat.

for military purposes. The value of such equipment has been shown on various flights, among them, the transatlantic flight of the NC-4 in 1919, the flight of the seaplane *Ne Plus Ultra* from Spain to Argentine in 1925, and on other occasions. Planes equipped with radio direction finders are enabled to obtain bearings for navigational and other purposes from any radio signals intercepted, and thus need not cause additional interference themselves. Rotating coil direction-finding loops have been used on our rigid airships as well as in the earlier Naval flying boats largely of wooden construction. Growing use of metal in airplane construction has rendered such rotating coils inside the hull ineffective in modern planes. By increasing the sensitivity of receivers, however, fairly good results have been obtained with smaller rotating loops projected out of the fuselage, but such loops are objectionable because of their wind resistance. Another method of direction finding in flight employs one or more fixed coils placed around portions of the wing or airplane fuselage and requires

turning and orienting of the entire plane in order to obtain bearings. This method is open to the objection that a plane must



Courtesy Herbert Photos, Inc.

Fig. 44—Marconi Type AD-6 Radio Installation in British D.H. 66 *Hercules* Passenger Airliner.

frequently veer off its course and possibly make complete turns while taking bearings. A more convenient method for use with shielded metal planes is the Bellini-Tosi system, where two

simple loop systems at right angles to each other are placed about the wings or suspended from other convenient parts of the ship, and connect inside the hull to a goniometer in which the field is reproduced and its direction determined with a small rotating search coil which connect to the receiving equipment in the same manner as does a large rotating loop. This latter system has the advantage that bearings on any station may be quickly taken and repeated any number of times without requiring a change in the plane's heading. The Bellini-Tosi system has been used with good success on a number of foreign installations,

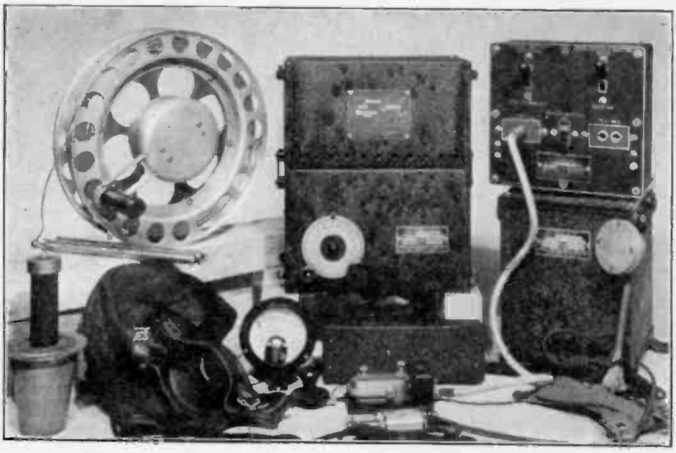


Fig. 45—10-Watt R.C.A. Aircraft Radio Equipment, Model ET-3652.

among them the airship *Norge* and the *Ne Plus Ultra*. Fig. 43 shows the arrangement of the fixed external loops on this flying boat.

The placing of direction-finding equipment on aircraft not only requires highly trained personnel among thecrew, but the obtainable accuracy and range of bearings is handicapped by the relatively unfavorable conditions aloft. These drawbacks are avoided if the direction-finding equipment can be placed at favorable locations on the ground, and manned by capable specialists. This system is in general use on the British airways, where planes are enabled at any time to obtain simultaneous bearings from direction-finding stations located at Croydon, Lympne, and Pulham. It is said that the total time required to furnish an airplane with its bearing does not exceed two minutes from the time the

plane starts sending its 30-second test signal until it has received its bearing or position.

The directional radio beacon or radio "range," as developed in this country jointly by the Army Air Service and the Bureau of Standards, has the main advantage that nothing but regular receiving equipment is required on the plane, and from the pilot's standpoint is the most easily applied of all methods. The radio beacon is of value not only for navigation on our airways but also has proved its worth as a dependable guide between California and Hawaii; Lieuts. Maitland and Hegenberger received great assistance from these signals, and Arthur Goebel ascribed his

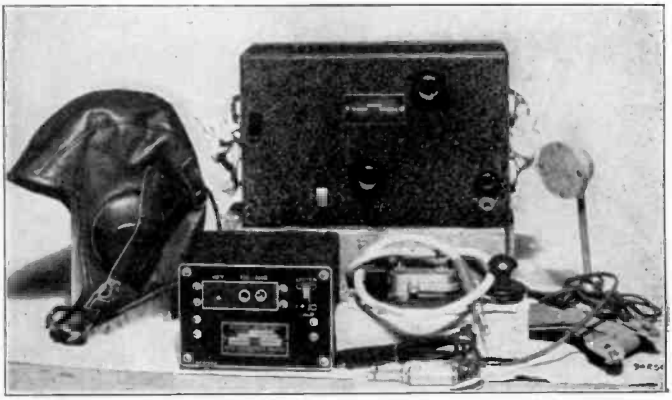


Fig. 46—300-Watt R.C.A. Equipment, Model ET-3654, Showing Receiver and Auxiliaries.

Dole flight victory primarily to his constant guidance by the radio beacon.

L. Commercial Aircraft Radio Equipment

In Europe there have existed for many years commercial lines of aircraft radio apparatus, the most prominent of which has been developed by the British Marconi Company; their most widely used set, type AD-6, is shown in Fig. 44, installed in a large British passenger plane on the England-Egypt-India air route. The transmitter is rated at 150 watts tube input, and has a transmitting range between 100 and 200 miles, both telegraphy and telephony being provided. The upper portion of the cabinet is occupied by a 5-tube receiver, employing two stages of radio-frequency amplification. An interesting feature of

this equipment is provision for full remote control by means of mechanical Bowden cable attachments, so that the equipment may be placed out of the way and operated from the pilot's cockpit.

The Radio Corporation of America has recently placed on the market commercial aircraft radio equipment of three different sizes, giving output ratings of 10, 100, and 300 watts. Both telephone and telegraph communication is provided, in the frequency band between 2250 and 2750 kc. Power supply both for transmitters and receivers is furnished by wind-driven generators,

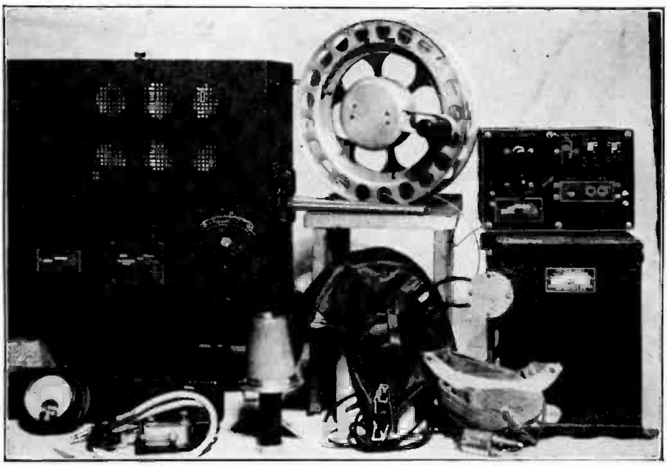


Fig. 47—300-Watt R.C.A. Equipment, Model ET-3654, Transmitter and Related Components.

and trailing wire antennas of about 100 feet in length are employed. Fig. 45 shows the components of the 10-watt equipment, except the receiver; the combined weight of the 10-watt equipment is 86½ lbs.

The 100-watt set, model ET-3653, is designed to cover up to 300 miles by CW telegragh and up to 75 miles or more by telephony; the total weight of this equipment is 133 lbs. A 5-tube receiver with interchangeable coils is a part of this equipment.

The components of the 300-watt equipment model ET-3654, are shown in Figs. 46 and 47. The combined weight of this equipment is 202 lbs., and the range is given as 500 miles for CW and 200 for voice communication. Eight 50-watt tubes model UV-211 are used in the transmitter. The receiver contains five

tubes, and is similar to the one employed with the 10-watt equipment. Both the 100- and the 300- watt installations provide for interphone communication between the radio operator and the pilot; in addition, the 300-watt equipment may be operated at will by the pilot by means of an auxiliary remote control unit, shown with the receiver in Fig. 47.

Separate equipment for merely receiving purposes has been developed for commercial airplanes wishing to avail themselves of the weather broadcast and directional beacon service being established on our airways. Frequencies around 300 kc. are employed for these uses.

M. Radio Aids for our Airways

In accordance with the provision of our Air Commerce Act our national airways and airmail routes are rapidly being provided with adequate radio aids. Among these ground facilities which are being installed under the supervision of the Airways Division, Bureau of Lighthouses, are Radio Stations for intercommunication between airports, ground radio stations for communications with aircraft, directional radio beacons, and low-power marker beacons. There is no doubt that with the provision of adequate ground facilities a great impetus will be given to the equipment of a large portion of our commercial airfleet with modern and efficient types of aircraft radio apparatus, with inevitable gains in the dependability and safety of air transportation.

THE REDUCTION OF ATMOSPHERIC DISTURBANCES*

By

John R. Carson

(American Telephone and Telegraph Company, New York City)

Summary—*In the decade or so during which the problem of eliminating or at least reducing atmospheric disturbances has been given serious and systematic study we have learned, more or less definitely, what we can and cannot do in this direction. For example, we know that there are definite and cannot do in this direction. For example, we know that there are definite limits to what can be accomplished by frequency selection. We know that directional selectivity is of substantial value, particularly when the predominant interference comes from a direction other than that of the desired signal, and we can calculate pretty well the gain to be expected from a given design.*

The object of this note is to analyze another arrangement which provides for high-frequency selection plus low-frequency balancing after detection. The broad idea of balancing out the interference is old, but I know of no general analysis of the arrangement. Furthermore the principle of balance has recently acquired fresh interest due to the system disclosed by Armstrong[1] in which high-frequency selectivity and low-frequency balancing are essential features. Armstrong's scheme is treated in more detail in the latter part of this paper.

The conclusions of this study are entirely negative, that is, no appreciable gain is to be expected from balancing arrangements. This is quite in agreement with the conclusion drawn over ten years ago by John Mills as a result of a rather extended experimental study made for the Bell System. In fact, as more and more schemes are analyzed and tested, and as the essential nature of the problem is more clearly perceived, we are unavoidably forced to the conclusion that static, like the poor, will always be with us.

I.

In any theoretical analysis of the static problem we have to face, at the outset, the difficulty inherent in our ignorance of the origin, wave form, and frequency distribution of static. If the problem can be treated as a statistical one this difficulty, as regards practical deductions, can be successfully avoided.[2] When we wish to analyze schemes involving low-frequency balancing after detection, there are serious difficulties in the way of this mode of treatment. Furthermore, it is desirable to have an independent mode of analysis. This is furnished by the following line of reasoning.

Any disturbance, whether signal or atmospheric, can, over

* Original Manuscript Received by the Institute, April 12, 1928.

[1] Proc. I.R.E., 16, 1, p. 15; Jan., 1928

[2] "Selective Circuits as Static Interference," *Bell System Tech. Jour.*, July, 1925.

any epoch or finite range of time t, be represented by the very general expression[3]

$$f(t) \cdot \sin(\omega t + \alpha(t)) \tag{1}$$

with the further restriction that $f(t) \geqq 0$ everywhere and ω is a constant at our disposal. Now let us suppose that (1) represents the disturbance after passing through an efficient selective circuit which confines the transmitted frequencies to those essential to the signal. Then $\omega/2\pi$ can be taken as any frequency inside the transmission band (preferably the carrier frequency of the signal) and f and α will be relatively slowly varying functions. Let us suppose, therefore, that we have a radio receiving system which employs efficient frequency selection before detection. The wave presented to the detector may then be represented by the general expression

$$W = S(t) \cdot \sin(\omega t + \theta(t)) + J(t) \cdot \sin(\omega t + \phi(t)) \tag{2}$$

where the first component represents the desired signal and the second interference. $\omega/2\pi$ is a constant, taken as the signal carrier frequency, and due to the action of frequency selection or filters,

$$\frac{1}{\omega} \frac{d}{dt} \theta(t) \text{ and } \frac{1}{\omega} \frac{d}{dt} \phi(t)$$

will be small compared with unity. In fact with small error we can write

$$\frac{d}{dt} W = \omega \left\{ S(t) \cdot \cos(\omega t + \theta(t)) + J(t) \cdot \cos(\omega t + \phi(t)) \right\}.$$

No other restrictions are imposed on the amplitudes or phase angles.

In the following we shall limit explicit consideration to radiotelegraph systems, whereby we are permitted to simplify the analysis somewhat by setting $\theta(t) = 0$ in (2). The extension of the analysis to radio telephony, however, presents no essential difficulties and the conclusions of the present study apply without modification to this case also.

II.

In analyzing schemes directed to solving the static problem, false conclusions, unduly favorable to the schemes under consideration, have been drawn, time after time, by reason of the

[3] See Appendix to this paper.

simple failure to compare the specific arrangement under analysis with a standard of reference. In the present discussion our standard of reference will be defined as follows. After the received wave is passed through a band filter, or a selective circuit such that the frequencies present in W, as given by (2), are confined to those essential for signaling purposes, the wave is demodulated or detected by a "homodyne" of carrier frequency $\omega/2\pi$. The detected output is then represented by

$$W'=\tfrac{1}{2}S(t)+\tfrac{1}{2}J(t)\cdot\cos(\phi). \tag{3}$$

Possibly this "reference system" requires a word more of explanation. At the transmitting station let the low-frequency signal $S(t)$ modulate a carrier wave represented by $\sin \omega t$, where $\omega/2\pi$ is the carrier radio frequency. The modulated output is then given by the expression

$$S(t)\cdot\sin\omega t.$$

Now let us suppose that $S(t)$ is representable by a series of sinusoidal terms (in the limit a Fourier's integral); that is, suppose

$$S(t)=\sum a_m \sin(\omega_m t+\theta_m).$$

Then by a well-known trigonometric formula, the modulated output is analyzable into two side bands

$$\tfrac{1}{2}\sum a_m \cos[(\omega-\omega_m)t-\theta_m]-\tfrac{1}{2}\sum a_m \cos[(\omega+\omega_m)t+\theta_m].$$

In one side band the frequency is less than that of the carrier wave; in the other greater.

We now suppose that by means of filters or otherwise one side band is suppressed and only one transmitted; say the lower side band. At the receiving station the unmodulated carrier wave $\sin \omega t$ is restored and it, together with the transmitted side band, impressed on the input circuit of a square-law demodulator. The demodulated output is then

$$\begin{aligned}&\tfrac{1}{2}\sin\omega t\sum a_m\cos[(\omega-\omega_m)t-\theta_m]\\&=\tfrac{1}{4}\sum a_m\sin[(2\omega-\omega_m)t-\theta_m]+\tfrac{1}{4}\sum a_m\sin(\omega_m t+\theta_m).\end{aligned}$$

The first summation represents double radio-frequency waves, which can easily be suppressed in the low-frequency circuit by selective means. The second summation is simply the original low-frequency signal. This system of transmission, it may be remarked, is employed in transatlantic radio-telephony.

Returning to (3) it will be observed that in our standard of reference, the output is linear in signal and interference amplitudes, S and J, and that the ratio of interference to signal is

$$\frac{J \cos \phi}{S}. \tag{5}$$

Since the phase angle ϕ is entirely arbitrary, the mean value of the ratio is

$$\frac{2}{\pi}\frac{J}{S}. \tag{6}$$

Any scheme, proposed for the solution of the static problem, must, in order to prove in, show a smaller ratio of interference to signal.

In the case of radio-telephony, demodulation by the homodyne principle or its equivalent is essential for high quality. In telegraphy, however, the same requirement is not present. Suppose, therefore, we examine the case of a *square-law* detector. With such a device the low-frequency output is given by

$$\tfrac{1}{2}S^2+\tfrac{1}{2}J^2+SJ \cos(\phi). \tag{7}$$

Since the phase angle ϕ is uncontrollable and, in general, variable, the last term of (7) is equally likely to be positive or negative. For the case of very strong interference, (7) becomes

$$\tfrac{1}{2}S^2+\tfrac{1}{2}J^2 \tag{8}$$

while for weak interference it is

$$\tfrac{1}{2}S^2+SJ \cos(\phi). \tag{9}$$

Comparing with (6), the corresponding expression for our standard of reference, it is seen that, in both cases, the interference ratio is increased by square-law detection.

In the case of radio-telegraphy there is another mode of demodulation, namely *straight-line* or *linear rectification*. There seems to be a more or less prevalent belief that this method possesses advantages over square-law detection, particularly as regards intermodulation between signal and interference. This belief is not justified; in fact it is an erroneous inference from the relative difficulty of analyzing the rectified output of a complex wave, and the very complex character of that output itself. In order to analyze exactly the rectified output, the wave

form of the input wave must be exactly specified, this requiring information which is never available in practice. General and qualitative information, sufficient for our purposes, can, however, be deduced as follows.

Returning to the wave, W, as given by (2), as the wave impressed on the ideal straight-line rectifier, this can be written as

$$W = F \cdot \sin(\omega t + \psi(t)) \tag{10}$$

where

$$F = \sqrt{\{S^2 + J^2 + 2SJ \cdot \cos(\phi)\}} \tag{11}$$

and

$$F \cdot \sin\psi = J \sin\phi.$$

The output wave is then given by

$$W' = M \cdot W = M\{S \sin(\omega t) + J \sin(\omega t + \phi)\}, \tag{12}$$

where M is a *modulating wave* defined as *unity* when $\sin(\omega t + \psi) > 0$ and *zero* when $\sin(\omega t + \psi) < 0$.

In the idealized case when the interference is absent, the modulating function of equation (12) is given by

$$M = \tfrac{1}{2} + \sin(\omega t) + \tfrac{1}{3}\sin(3\omega t) + \tfrac{1}{5}\sin(5\omega t) + \cdots \tag{13}$$

Comparing (13) with our standard of reference system it is seen that M differs from the demodulating homodyne $\sin(\omega t)$ only by the presence of the zero frequency and harmonics of the carrier frequency. Theoretically perfect demodulation, however, results.

When, however, the signal wave is complex and in addition interference is also present, the modulating function M and the demodulated output of the rectifier is vastly more complicated. Making, however, certain ideal assumptions—the most favorable possible to the method of demodulation under immediate consideration—it may be shown that the predominant term of the demodulated output is represented approximately by

$$\frac{m}{2}\{S(t)\cos(\psi) + J(t)\cos(\phi - \psi)\}. \tag{14}$$

Here m is itself a variable depending on the relative amplitudes and phases of the signal and interference. In addition the phase angle ψ is an uncontrollable variable. In practice, in addition to the output, as given by (14) there are terms of distorted

frequencies which cannot be filtered out in the low-frequency circuit.

However, the analysis of the linear rectifier is much more simply effected by employing the following approximate expression for the demodulated low-frequency output:

$$W' = \tfrac{1}{2}\sqrt{S^2 + J^2 + 2SJ\cos(\phi)} \tag{15}$$

This is the *envelope* of the high-frequency disturbance and, it will be observed, is proportional to the square root of the output of the square law detector. This formula, while in general approximate, is quite sufficiently accurate for our purposes, and is indeed favorable to the linear rectifier.

III.

The foregoing completes our discussion of the elementary theory of demodulation with particular reference to the simultaneous presence of signal and interference, which is the critical case to be considered. It remains to apply this theory to low-frequency balancing arrangements.

Common to all balancing schemes, the receiving system must include, in addition to the radio-frequency signaling channel, an auxiliary channel of substantially the same frequency-band width and preferably located very close to the former in the frequency scale. This auxiliary channel must be quite sharply selective *against* the signal itself. On the other hand it is supposed to absorb, from atmospherics or other random disturbances, substantially the same amount of energy as the signal channel; indeed this requirement is essential to the theory of the operation of the arrangement.

The received waves, after passing through frequency selective circuits in the two channels are demodulated by separate devices, and the demodulated outputs are differentially combined in a common low-frequency receiver, or receiving circuit.

The idea of the operation of this device is very simple. If the desired signal is alone present the auxiliary channel does not affect reception since, by means of frequency discrimination, it is unresponsive to the signal frequencies. When signal and atmospheric interference, or static, are simultaneously present, the latter is supposed to be balanced out in the low-frequency circuit, since the two high-frequency channels will absorb substantially the same amounts of energy from the interference.

Let us, however, examine the operation of the system in more detail, in the light of the elementary analysis developed above.

Just as in (2), the high-frequency wave in the signal channel, after frequency selection, may be written as

$$W = S(t) \cdot \sin(\omega t) + J(t) \cdot \sin(\omega t + \phi(t)) \tag{15}$$

In the auxiliary channel the corresponding wave is

$$W_1 = J_1(t) \cdot \sin(\omega_1 t + \phi_1(t)) \tag{16}$$

ω_1 may be taken as a constant nearly equal to ω, their difference depending on the frequency separation between channels. The relation between J_1 and J and ϕ_1 and ϕ will depend on the wave form of the interference.

Now let us suppose that the waves, as given by (15) and (16) are demodulated by homodyne generators of frequency $\omega/2\pi$ and $\omega_1/2\pi$. Corresponding then to (3) the demodulated output from the signal channel is

$$\tfrac{1}{2}S(t) + \tfrac{1}{2}J(t)\cos(\phi) \tag{17}$$

while that from the auxiliary channel is

$$\tfrac{1}{2}J_1(t)\cos(\phi_1). \tag{18}$$

Subtracting (18) from (17) the resultant low-frequency output is

$$\tfrac{1}{2}S(t) + \tfrac{1}{2}J(t)\cos(\phi) - \tfrac{1}{2}J_1(t)\cos(\phi_1). \tag{19}$$

Now since the phase angles ϕ and ϕ_1 are both variable and uncontrollable, it follows that the two interference components are equally likely to add or subtract so that no gain by balancing results on the average.

Suppose, however, demodulation in both channels is effected by a square law detector. The differential low-frequency output is then

$$\tfrac{1}{2}S^2 + \tfrac{1}{2}(J^2 - J_1^2) + SJ \cdot \cos(\phi). \tag{20}$$

Let us assume further that $J^2 - J_1^2$ can be made negligibly small, a condition at least partially realizable. The output is then

$$\tfrac{1}{2}S^2 + SJ \cdot \cos(\phi). \tag{21}$$

It follows from (21) that the interference is effectively suppressed *in the absence of the signal.*[4] Comparison with (3), however, shows that, when the signal is present, the interference to signal ratio

[4] See, however, the concluding paragraph of this paper.

is just twice that obtainable with our reference standard circuit. Whether or not the suppression of interference in the absence of the signal compensates for the increased interference-to-signal ratio in the presence of the signal is an open question which can only be decided by practical experience. Furthermore the balance obtainable in practice will certainly be far from perfect. It is further to be observed that since homodyne demodulation, or its equivalent, is essential for telephonic signals, no gain by balancing is possible in radio-telephone transmission. An added disadvantage, it may be noted, that attaches to balancing schemes is that the receiving system must be responsive to a frequency range double that required for the usual method of reception.

If the analysis is extended to the case of straight-line rectifier demodulation by means of (15) the general conclusions are of the same character. In fact we have for the resultant demodulated output

$$\tfrac{1}{2}\sqrt{S^2+J^2+2SJ\cos(\phi)}-\tfrac{1}{2}J_1 \tag{22}$$

which, in the absence of the signal (spacing interval) becomes

$$\tfrac{1}{2}(J-J_1) \tag{23}$$

As in the case of the square law detector, the gain results only during the spacing interval and is obtained at the expense of an increased interference ratio during the marking interval.

IV.

The foregoing reasoning will now be applied to the receiving system proposed by Armstrong. His arrangement specifies demodulation by rectification. Its only essential difference from the corresponding balancing scheme discussed above is that in the normal absence of the signal (spacing interval) a wave of slightly different frequency is transmitted to which the auxiliary channel is responsive. Applying (15), we have in the presence of the signal (marking interval) the following expression for the demodulated output

$$\tfrac{1}{2}\sqrt{S^2+J^2 2SJ\cos(\phi)}-\tfrac{1}{2}J_1 \tag{24}$$

while during the spacing interval, we have

$$\tfrac{1}{2}J-\tfrac{1}{2}\sqrt{S_1{}^2+J_1{}^2+2S_1J_1\cos(\phi_1)}. \tag{25}$$

Comparing (22) with (24) it is clear that no gain results, in the marking interval, over that procured with an ordinary balance: In fact, during this interval the outputs are identical. In the spacing interval, however, a comparison is quite unfavorable to the Armstrong scheme. For, in the usual balance system, it is theoretically possible to balance out substantially interference in the absence of the signal. In the Armstrong system, however, interference occurring during a spacing interval may result in a false signal, depending on the intensity of the interference, and on uncontrollable, variable phase angles.

There is another feature of the Armstrong arrangement which must be taken into account in comparing it with standard systems. This is that, as compared with non-balancing arrangements, the Armstrong system requires a doubling of the power radiated and a doubling of the receiving frequency band. *By discarding the balancing feature and the spacing wave, it should be possible to transmit by usual circuits, the signal message and a repetition thereof with the same power and the same frequency requirements of the receiving system.* It would be extremely interesting to have a comparison of such a system with that proposed by Armstrong.

In the foregoing discussion the possibility of balance in the absence of signal (spacing interval) was treated optimistically in order that the conclusions of the analysis should be conservative, and for the sake of simplicity. That the balance ordinarily obtainable in the spacing interval, even with the ideal rectifier, is likely to be quite imperfect may be seen by the following discussion of a case of probably frequent occurrence touched on by Englund[5] in his discussion; namely, where the interference consists of two or more overlapping disturbances. To consider this case, the interference in the receiving channel may be written as

$$J \sin(\omega t+\phi)+J' \sin(\omega t+\phi')$$

while in the auxiliary balancing channel it is

$$J_1 \sin(\omega t+\phi_1)+J_1' \sin(\omega t+\phi_1').$$

The differential rectified output is then approximately

$$\sqrt{J_2+J'^2+2JJ' \cos(\phi-\phi')}-\sqrt{J_1^2+J_1'^2+2J_1J_1' \cos(\phi_1-\phi_1')}.$$

Now even if we grant the possibility of balancing completely the terms $(J-J_1)$ and $(J'-J_1')$ the presence of the uncontrollable

[5] Proc. I. R. E., 16, 1, p. 27; Jan. 1928.

variable phase term in the preceding makes it clear that the balance will, in general, be imperfect for the case of overlapping disturbances. As stated above, it is reasonable to suppose that this case is of frequent occurrence.

Appendix

Formula (1) can be established as follows: Any disturbance, supposed to exist only over a finite interval of time, t, can be formulated as the Fourier integral

$$I = \int_0^\infty F(\lambda) \sin[\lambda t + \theta(\lambda)] d\lambda.$$

Now write $\lambda = \omega + \mu$ where ω is a constant at our disposal; we get

$$\begin{aligned} I &= \sin \omega t \int_{-\omega}^\infty F(\mu+\omega) \cdot \cos\,[\mu t + \theta(\mu+\omega)] d\mu \\ &\quad + \cos \omega t \int_{-\omega}^\infty F(\mu+\omega) \cdot \sin[\mu t + \theta(\mu+\omega)] d\mu \\ &= I_c \sin \omega t + I_s \cos \omega t \\ &= f(t) \sin\,[\omega t + \alpha(t)] \end{aligned}$$

where

$$f^2(t) = I_c^2 + I_s^2$$
$$\cos \alpha(t) = I_c / f(t).$$

The preceding analysis is entirely formal; its practical significance enters in only when we suppose that the disturbance has passed through an efficient selective network which confines, more or less efficiently, the transmitted frequencies to a finite band, say $\omega_1 \leqq \omega \leqq \omega_2$. In this case

$$I = \int_{\omega_1}^{\omega_2} F(\lambda) \sin\,[\lambda t + \theta(\lambda)] d\lambda.$$

If we now write $\lambda = \omega + \mu$ when ω lies within the transmitted band of frequencies, the same analysis shows that if ω is large compared with $\omega_2 - \omega_1$, $f(t)$ and $\alpha(t)$ are relatively slowly varying functions.

As stated, the preceding analysis applies rigorously to all types of disturbances. In the case of a radiotelegraph signal, however, it is convenient and permissible to start with the approximate expression

$$S(t) \cdot \sin \omega t$$

where $\omega/2\pi$ is the carrier frequency and $S(t)$ a low-frequency function $\geqq 0$.

THERMOSTAT DESIGN FOR FREQUENCY STANDARDS*

By

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THE means usually employed for maintaining constant the temperature of a body employs a device, responsive to small variations from a given temperature, which automatically varies the rate of heating whenever the temperature departs from this prescribed value. For the operation of such controlling means it is necessary for the temperature of the responding device to vary between a value slightly above its normal operating value and one slightly below, since it is only through such variation that any control can be effected. Of necessity the temperature of the material immediately surrounding the responding element fluctuates even more, whether it be a fluid bath or any other medium.

The body which is to be maintained at constant temperature and the controlling element often bear the same thermal relation to the heater. If this is the case, the same temperature variations that operate the responding element are applied to the region it is desired to control. Sometimes the responding element is mounted within the controlled region, which from this standpoint is an undesirable arrangement. In order to reduce the variation in such cases, it is necessary to employ especially sensitive responding elements and to make their heat capacity small in comparison with that of the controlled object.

The same end may be attained by so designing the thermal system that the variations reaching the object to be controlled are materially reduced below those necessarily existing at the responding element. To accomplish this a layer of material, especially chosen for the property of attenuating temperature variations, is interposed between the object to be controlled and the region about the responding element.

The resulting arrangement of the thermostat wall is shown in Fig. 1. The four essential layers consist of a layer of thermal insulation, a heater as well distributed as possible immediately

* Original Manuscript Received by the Institute, May 7, 1928.
Communication from the International Union of Scientific Radio-telegraphy.

within the insulating wall, a distributing layer for equalizing temperatures parallel to the surface, and what we shall call an "attenuating layer" for reducing the effects of the time variations of temperature which exist in the distributing layer.

The insulating and heating layers need no comment except that it is well to keep the simplest possible symmetry in order to aid in the distribution of heat. From this standpoint there is a real advantage in using a cylindrical shape as indicated by the sketch Fig. 1.

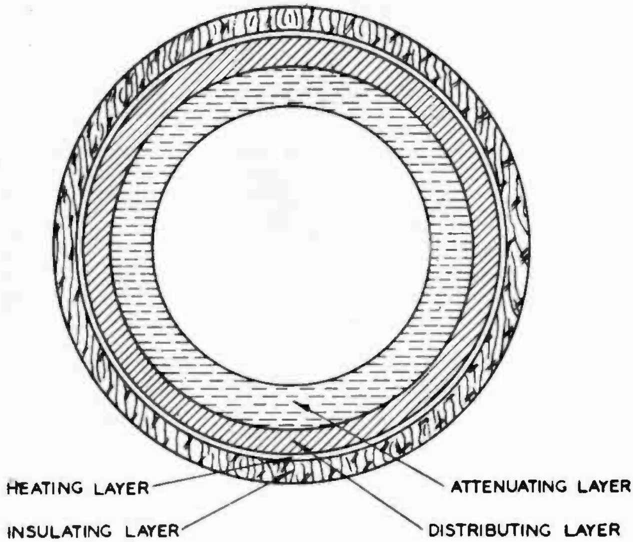

Fig. 1.

The distributing layer should have high thermal conductivity parallel to the surface and a low heat capacity, in order to equalize the temperature over the surface completely and quickly and to permit the responding element to operate as frequently as possible. A stirred bath of light oil has both of these properties and is satisfactory where space and conditions permit the use of a liquid, but a wall of highly conducting metal with low density, like aluminum, is more desirable from most standpoints and is especially effective if laminated, with the layers separated by thin insulation, like paper.

The attenuating layer should be made of material having large heat capacity and low conductivity, the effectiveness depending

on the ratio DH/C, where D is the density, H is the specific heat, and C is the conductivity. If these constants for any substance are known, the temperature variations at any point in an infinite wall (or any wall of large radius) can be expressed as

$$T = T_0\, e - \sqrt{\frac{DH\omega}{2C}}\, l$$

where T_0 is the applied temperature variation and T is the variation at any point, distance l from the surface. The constant ω is 2π times the frequency of thermostat operation. In Table I a list of ordinary substances is given with the attenuation

TABLE 1

ATTENUATION CONSTANT $\sqrt{\frac{DH}{2C}}$ FOR A FEW ORDINARY SUBSTANCES

Substance	Density-D	Specific Heat-H	Conductivity-C	$\sqrt{\frac{DH}{2C}}$
Asbestos	3.0	0.20	0.00019	40.
Wood (Cedar ⊥ grain)	0.5	0.42	0.00009	34.
Vulcanite	1.8	0.33	0.00042	27.
Glycerine	1.26	0.54	0.0006	25.
Turpentine	0.87	0.42	0.0003	25.
Water	1.00	1.00	0.001	22.
Paraffin	0.8	0.69	0.31	22.
Rubber	0.9	0.4	0.00045	20.
Sulphur	2.0	0.18	0.00045	20.
Alcohol	0.79	0.5	0.0005	20.
Phenol Fibre	1.35	0.35	0.0006	20.
Wool Felt	0.32	0.3	0.00013	19.
Cellotex	0.26	0.26	0.00014	16.
Silocel (Powder)	0.22	0.24	0.00013	14.
Porcelain	2.3	0.26	0.0025	10.8
Glass	3.0	0.15	0.002	10.6
Silica	2.2	0.19	0.002	10.2
Mercury	13.6	0.03	0.02	3.2
Air	0.0013	0.24	0.00005	1.8
Iron	7.86	0.1	0.14	1.7
Lead	11.3	0.03	0.092	1.4
Aluminum	2.7	0.22	0.5	0.77
Hydrogen	0.000090	3.4	0.0003	0.71
Copper	8.9	0.09	1.0	0.63
Silver	10.5	0.055	1.0	0.54

constant $\sqrt{\frac{DH}{2C}}$ computed from constants found in various tables.

It has been found that the best attenuating property is obtained when the constants in the attenuating wall are tapered so that on the inside the heat capacity is a maximum and on the outside the thermal conductivity is a minimum. This can be accomplished, in a laminated structure using two materials, by using laminae of varying thickness so arranged that one material predominates on one side of the wall and the other material predominates on the other side. The effectiveness of the attenuating wall increases rapidly with frequency of thermostat operation

as appears in the above expression for resulting temperature variation.

The temperature and temperature variation at different parts of an ideal thermostat wall are shown in the graph Fig. 2. The

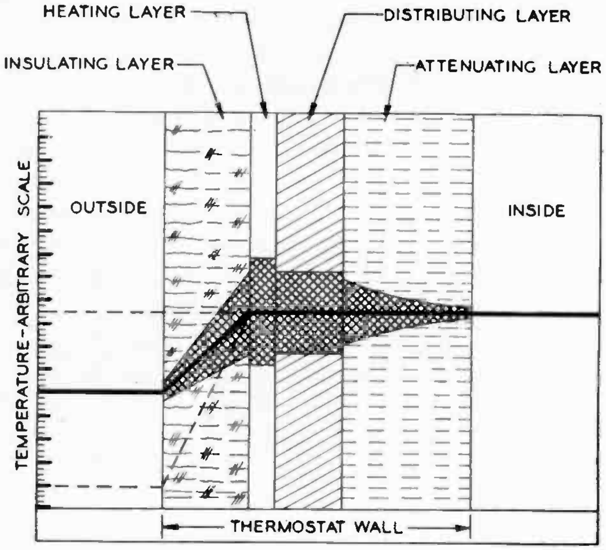

Fig. 2.

heavy line represents the average temperature and the heavy shading the amount of variation. In addition to the properties referred to above, discontinuities in temperature variations are

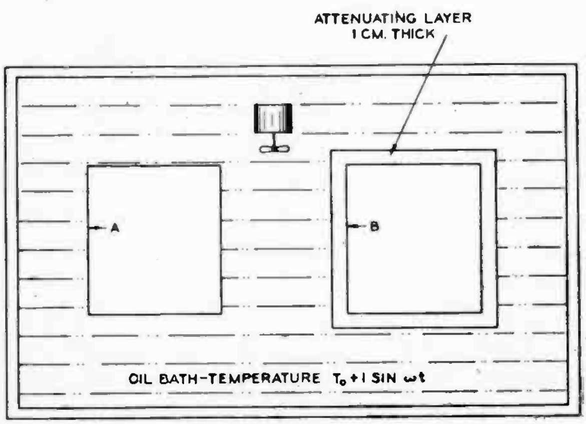

Fig. 3.

indicated between the layers. Such discontinuities occur at each boundary and assist materially in reducing variations in temperature, especially if a laminated structure is used.

As an example of what can be gained by the use of an attenuating layer, consider an oil bath in which are immersed two containers, as shown at *A* and *B* in Fig. 3, one being in direct contact with the bath and the other separated from it by an attenuating wall, as described, one centimeter thick. The temperature variations applied to container *A* are, of course, those of the bath itself. Those applied to container *B* are considerably reduced by the attenuating layer as indicated by the table in Fig. 3. When the period of thermostat operation is one minute or less, and when an attenuating layer with tapered constants as previously described is used, the temperature variation is reduced in the ratio of at least 10,000 to one.

Discussion on

RECENT DEVELOPMENT IN LOW POWER AND BROADCAST TRANSMITTERS* (I. F. BYRNES)

F. M. Ryan†: Mr. Byrnes is to be complimented on having given some quantitative data on harmonic radiation from radio transmitters. The reduction of such radiation is an important problem and has been given far too little attention in the literature.

It is noted that Mr. Byrnes expresses the magnitude of harmonics in terms of the ratio of the power of the fundamental to that of the harmonic. The limiting value of this factor is, of course, what the design engineer requires in determining the attenuation he must provide to currents of these unwanted frequencies. It should be kept in mind, however, that the interference caused by harmonic radiation is determined solely by the absolute value of the radiated power. For example, with a fundamental-to-harmonic power of 30,000 to 1 in the case of a 2000-watt transmitter the same degree of interference will be experienced as with a fundamental-to-harmonic ratio of 3000 to 1 in a 200-watt transmitter, each producing a harmonic field strength of about 1800 microvolts per meter at a distance of one mile.

It is interesting to note that in order to limit the radiation of the second harmonic to an absolute value equivalent to the figure mentioned by Mr. Byrnes (0.067 watt) it would be necessary in the case of a 50-kw radio transmitter to attain a fundamental-to-harmonic power ratio of 750,000 to 1. With this degree of harmonic reduction, the field strength at one mile would again be 1800 microvolts per meter. As a matter of fact, tests of the Western Electric 50-kw Radio Broadcasting Transmitter made at Whippany, New Jersey, show a considerably higher degree of harmonic reduction, the field strength of the harmonic of the greatest amplitude being less than 500 microvolts per meter at one mile distance from the station with a fundamental field strength of more than 1,500,000 microvolts per meter. This corresponds to a ratio of fundamental power-to-harmonic power of more than 10,000,000 to 1 or 70 TU.

I. F. Byrnes‡: The reduction of harmonic output and the best method expressing the magnitude of harmonics from trans-

* Presented at New York meeting of the Institute, April 4, 1928. Proc. I. R. E., 16, 5, p. 614; May, 1928.
† Bell Telephone Laboratories, New York City.
‡ Radio Engineering Dept., General Electric Co., Schenectady, N. Y.

mitting sets are being given considerable attention at the present time. While it is true that the interference caused in a particular receiver at a certain distance from the transmitter is determined by the absolute value of harmonic power, unless a ratio is used to express the difference between the fundamental and some harmonic, it is difficult to compare quickly the merit of transmitters of different power outputs. It is also true that with a given type of transmitting circuit, having the same overall characteristics for different output ratings, the higher powered set is certain to produce harmonics of greater amplitude.

In the case of broadcast transmitters, it should be realized that the more remote location of high power sets automatically mitigates disturbance due to harmonics, with respect to the number of people annoyed by such harmonics. For example, a 5-kw broadcasting transmitter located in or near a large city and operating on the lower broadcasting frequencies might cause considerable interference on its second harmonic. If we moved this station to a point 20 or 30 miles from the city and increased its power to, say 50 kw, the absolute value of the harmonic may be increased many times without causing any more interference than in the first case, to the same population group.

The design of transmitting sets for commercial or military application presents more difficulty with respect to harmonic reduction than in the case of broadcasting or fixed land stations. In many commercial transmitters which cover a wide frequency band, the frequency we may wish to suppress under one condition is the frequency on which maximum radiation is desired under some other condition. This of course makes the design of output filters a difficult problem. It is fortunate that broadcasting transmitter design permits us to use a fixed transmitting frequency and carefully designed low-pass filters, traps, etc., in the various circuits.

BOOK REVIEW

The World of Atoms. . . By Arthur Haas, translated by Horace S. Uhler. Published by D. Van Nostrand Company, New York, 1928. pp. xi+139, 31 illustrations. Price $3.00.

This little book is decidedly to be recommended to all who, having some knowledge of elementary physics, wish to inform themselves concerning the remarkable advances in atomic theory that the past few years have witnessed. In many respects it resembles the same author's earlier book, "The New Physics," but it is considerably more comprehensive, and traces the subject down to the latter part of 1927. It is based upon a course of lectures given in Vienna. Concerning these lectures the preface states that "they were intended to present to a lay public the achievements of modern atomic physics in as brief and yet thorough a manner as possible, and at the same time in an easily understandable form." The titles of the ten chapters will serve to indicate the nature of the subject-matter: Matter and Electricity; The Building-Stones of Atoms; Light-Quanta; Spectra and Energy Levels; The Elements; The Atom as a Planetary System; Molecules; Radioactivity; Transformations of the Elements; Wave Mechanics of the Atom.

In each chapter there is a clear and logical development of the subject from simple phenomena to the more advanced ideas of the present day. The last chapter is entirely new, having been written especially for the American edition. In it a brave attempt is made to present in popular style the essence of the new wave-mechanics. Considering the difficulty of the subject and the brevity of the treatment, as much success has been achieved as could be expected. In various other parts of the book as well the lay reader will probably wish that the ideas had been more fully explained.

In so comprehensive a treatment complete accuracy can hardly be expected. The reviewer is of the opinion that the discovery of the cathode rays, p. 13, should be attributed to Plücker rather than to Hittorf. On p. 86 is the statement that "crystals represent giant molecules." The present view, however, is that while this is in general true of inorganic crystals, still in many organic crystals there is evidence of the separate existence of individual molecules within the crystal.

Even though it is to be expected that in a book of this type the names of many investigators must necessarily be omitted,

still surely in referring to the cathode-ray parabolas the author should have mentioned Sir J. J. Thomson as well as Aston.

The book is beautifully printed and well illustrated. A high tribute should be paid to Professor Uhler for the extraordinarily good translation into English. Professor Haas's large circle of friends in America will be still further increased by this latest contribution of his to the literature of popular science.

W. G. Cady.

BIBLIOGRAPHY ON AIRCRAFT RADIO*

By

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(Bureau of Standards, Washington, D.C.)

The rapid development of commercial aviation has brought increased interest in the possibilities of radio as an aid to air navigation. In order that persons working in this field may have a means of ready reference to the work already done, the references on file in the Bureau of Standards have been compiled into this bibliography. These references have been in part published in the monthly reference lists.[1] They give a fairly complete bibliography on the subject up to June, 1928. As a revision of this bibliography may be published at a later time the Bureau of Standards would be glad to receive any criticisms, corrections, or additions to this list. The references are classified by subjects and under each subject the references are in chronological order. The classification is according to "A Decimal Classification of Radio Subjects—An Extension of the Dewey System,"[2] Bureau of Standards Circular No. 138. The part of the general classification of radio subjects used here is as follows:

R520 Aircraft
R520.1 Research
R520.3 Terminology and symbols
R520.4 Lectures
R520.5 Publications
R520.6 Societies
R520.7 Education and Training
R520.9 Historical
R521 Receiving on aircraft
R522 Transmitting from aircraft
R523 Receiving from aircraft
R524 Transmitting to aircraft
R525 Antennas

* Original Manuscript Received by the Institute, June 4, 1928. Publication approved by the Director of the Bureau of Standards of the U. S. Department of Commerce.

[1] A monthly list of references to articles on radio subjects appearing in periodicals has been published for several years by the Bureau of Standards in the Radio Service Bulletin, a publication of the Department of Commerce; Subscription 25 cents per year from the Superintendent of Documents, Government Printing Office, Washington, D.C. Publication of these monthly lists in the Proceedings has begun recently.

[2] Copies of this circular may be obtained for 10 cents from the Superintendent of Documents, Government Printing Office, Washington, D.C.

R526 Radio as navigation aid
R526.1 Beacon systems
R526.2 Direction finders
R526.3 Field localizers
R526.4 Altimeters

R520. Aircraft Radio

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R323 Le Marquand, H. Sous-marins et ondes Hertziennes (submarines and Hertz waves). *QST Francais et Radio-electricite Reunis*, **8**, pp. 40–42; December, 1927.

(Description of apparatus used on submarines including experiments with different types of antennas.)

R325.1 Kenn, R. Wireless direction finding and directional reception (book, 2nd edition). Publishers, Iliffe & Sons, Ltd., London, 1927. Price 21 shillings. Abstract in *Wireless World & Radio Rev.*, **22**, p. 10, January 4, 1928.

(Methods and apparatus used in direction finding.)

R330 Forstmann and Schramm. Die Elektronenrohre (book). Publishers, Schmidt & Co., Berlin, 1927. Reviewed in *Experimental Wireless* (London), **4**, p. 760; Dec., 1927.

(Treatise on electron tubes.)

R330 The UX250–CX350 tube. *QST*, **12**, p. 36, Apr. 1928.

(Characteristics for this type tube—25-watt power.)

R330 The Frenotron valve—A Vienna novelty. *Experimental Wireless* (London), **5**, p. 214; April, 1928.

(New type of detector to be used as a stabilizer.)

R330 Hanna, C. R., Sutherlin, L., and Upp, C. B. Development of a new power amplifier tube. Proc. I.R.E., 16, pp. 462–75; April, 1928.

(Description of the development of the power tube UX-250. Properties and limitations as well as design information applicable to these tubes and their circuits are discussed.)

R330 Wheeler, H. A. Measurement of vacuum-tube capacity by a transformer balance. Proc. I.R.E., 16, pp. 476–81; Apr., 1928.

(Description of complete portable apparatus for measurement of direct capacities of electron tubes in laboratory or factory testing. Tube capacity compared with standard variable condenser by means of transformer-balance (Neutrodyne) circuit.)

R330 Walsh, L. A direct-capacity bridge for vacuum-tube measurements. Proc. I.R.E., 16, pp. 482–86; Apr., 1928.

(Bridge is described which permits the measurement at a single setting of a capacity associated with other capacities in a system having more than 2 terminals, such as grid-plate capacity of an electron tube.)

R330 Hoch, E. T. A bridge method for the measurement of inter-electrode admittance in vacuum tubes. Proc. I.R.E., 16, pp. 487–93; Apr., 1928.

(Description of Colpitts-Campbell bridge as applied to measurement of direct admittances in electron tubes. Bridge circuit for measurement of direct capacity and conductance given. Data given on several tubes.)

R331 Simon, H. Einiges uber Empfangerrohren (something on receiving tubes). *Telefunken Zeitung*, 11, pp. 38–50; October, 1927.

(Construction and description of thoriated filament electron tubes.)

R334 The Cossar screened valve. *Wireless World & Radio Rev.*, 21, pp. 817–18; Dec. 21, 1927.

(Characteristic curves and practical hints for best conditions of operation.)

R334 Warner, J. C. Some characteristics and applications of 4-electrode tubes. Proc. I.R.E., 16, pp. 424–46; April, 1928.

(Theory, construction and use of 4-electrode tubes.)

R334 Hall, N. R. Characteristic curves of the 4-electrode valve. *Experimental Wireless* (London), 5, pp. 198–200; Apr., 1928.

(Curves given for British 4-electrode electron tubes.)

R340 The power factor and capacity of the electrodes and base of triode valves with special reference to their use in thermionic voltmeters. *Experimental Wireless* (London), 5, p. 16; January, 1928.

(Table giving capacity and power factor of several types of tube bases.)

R341 Kuhlman, J. H. and Barton, J. P. The vacuum-tube rectifier *Jnl.* A. I. E. E., 47, pp. 17–24; January, 1928.

(Design of rectifier for use as B power supply; determination values of inductance and capacity for filter circuit—uses electron-tube voltmeter.)

R341 Loftin, E. H. and White, S. Y. Direct-coupled detector and amplifiers with automatic grid bias. Proc. I.R.E., 16, pp. 281–86; March, 1928.

(System for direct coupling of electron tubes to give composite detection and amplification which is free from electrical and acoustical feed-back effects.)

R342 Vreeland, F. K. On the distortionless reception of a modu-

lated wave and its relation to selectivity. PROC. I.R.E., **16**, pp. 255–80; Mar., 1928.

(Description of an amplifier giving uniform amplification over entire width of band also description of band selector having rectangular frequency characteristic. Various applications of these to broadcast reception.)

R342 Marcus, A. A triode amplifier for small direct currents (abstract). *Physical Rev.*, **31**, p. 302; Feb., 1928.

(Measurement of ionization currents and piezo-electric currents of magnitudes considerably below range of galvanometer by use of electron-tube amplifier.

R342 Terman, F. E. The inverted vacuum tube, a voltage reducing power amplifier. PROC. I.R.E., **16**, pp. 447–61; Apr., 1928.

(By the interchange of functions of grid and plate of an electron tube a voltage reducing power amplifier is obtained. Theory given.)

R342.15 Muller and von Ardenne. Transformatoren—Verstarker. (transformers—amplifiers) (book). Publishers, Schmidt & Co., Berlin, 1927. Reviewed in *Experimental Wireless* (London), **4**, p. 760; Dec., 1927.

(Treatise on radio transformers and amplifiers.)

R342.15 Osborn, B. K. Data on the voltage amplification of r.f. transformers. *Radio Engineering*, **8**, pp. 24–25; Apr., 1928.

(Apparatus used and operations involved for testing of r.f. transformers.)

R342.6 Runge, W. Der abgestimmte Hochfrequenzverstarker (the tuned radio frequency amplifiers). *Telefunken Zeitung*, **11**, pp. 50–63; October, 1927.

(Theory of radio-frequency amplifiers with special reference to neutralization.)

R342.6 Inglis, C. C. Good quality in high-frequency amplifiers. *Experimental Wireless* (London), **5**, pp. 132–33; Mar., 1928.

(Calculation of effect of high impedance electron tubes on the sharpness of resonance of tuned circuits connected to them.)

R344 Prince, D. C. and Vogdes, F. B. Vacuum tubes as oscillation generators. General Electric *Rev.*, **31**, pp. 97–98; Feb., 1928.

(Design of simpler electron-tube circuits. Difference between Hartley and Colpitts circuits.)

R344 Heim, W. Dispersionmessungen im Gebiete kurzer elektrischen wellen (Dispersion measurements in direction of short electric waves). *Zeitschrift für Hochfrequenztechnik*, **30**, pp. 176–83; Dec., 1927.

(Description of electron-tube generator and application to short wave measurements.)

R344 Reed, M. Parasitic oscillations in the case of a tuned-anode oscillator. *Experimental Wireless* (London), **5**, pp. 135–47; March, 1928.

(Conditions under which parasitic oscillations may occur and discussion of their cause.)

R344 Prince, D. C. and Vogdes, F. B. Vacuum tubes as oscillation generators. General Electric *Rev.*, **31**, pp. 147–52; March, 1928.

(Special considerations of design and operation of generating circuits.)

R344.3 Hollman, H. E. Transmitting on a wavelength of 3/4 of a meter. *Radio News*, 9, pp. 1143–45; April, 1928.

(Description of apparatus used by author for transmission of telephony on wavelength of 75 cm.)

R348 Knowles, D. D. The grid-glow tube relay. *Electric Jnl.*, **26**, pp. 176–78; April, 1928.

(Description of a relay which has an amplification factor of 10^8 under certain conditions. Gives miscellaneous applications of this relay.)

R351 Rodwin, G. and Smith, T. A. A radio frequency oscillator for receiver investigations. PROC. I.R.E., **16**, pp. 155–65; Feb., 1928.

(Description of modulated radio frequency oscillator with means for obtaining radio frequency outputs for measuring purposes.)

R360 Wheeler, H. A. Automatic volume control for radio receiving sets. PROC. I.R.E., **16**, pp. 30–39; January, 1928.

(Uses rectified carrier voltage to adjust grid bias of radio-frequency amplifier tubes.)

R374 Schleede, A. and Biggish, H. Zusammenfassender Bericht—Der Kristalldetektor (Joint report—Crystal detectors). *Zeitschrift für Hochfrequenztechnik*, **30**, pp. 190–93; December, 1927.

(Theory of natural and manufactured crystals for use as radio detectors.)

R376 Wente, E. C. and Thuras, A. L. A high efficiency receiver for a horn type loudspeaker of large power capacity. Bell System Technical *Jnl.*, **7**, pp. 140–53; Jan., 1928.

(Telephone receiver of moving coil type. Used in Movietone and Vitaphone.)

R376.3 Story of the hornless loudspeaker. *Wireless World & Radio Rev.*, **21**, pp. 806–10; Dec. 21, 1927.

(Historical survey 1879 to 1927 of development of free-edge, fixed-edge, and inertia-controlled cone loudspeakers.)

R376.3 Meyer, E. Uber die nichtlineare Verzerrung von Lautsprechern und Fernhoren (On the non-linear distortion of loudspeakers and receivers). *Elektrotechnische-Nachrichten Technik*, **4**, pp. 509–15; December, 1927.

(Results of tests carried out by means of a sound compensation device which measures the strength of the overtones in proportion to the strength of fundamental tones.)

R376.3 Hanna, C. R. Abridgment of loudspeakers of high efficiency and load capacity. *Jnl.* A. I. E. E. **47**, pp. 253–57; April, 1928.

(Design of high quality horntype loudspeaker with moving coil driving elements considered. Calculation of efficiency and maximum output capacity from this type of speaker.)

R381 Smith, B. E. The design of variable condensers for high voltage operation. *QST*, **12**, pp. 49–51; March, 1928.

(Qualifications of condensers to withstand high voltages. Use in large transmitting stations.)

R381 Smith, B. E. The relation of condenser ratings to filter design. *Radio Engineering*, **8**, pp. 33–34; Apr., 1928.

(Explanation of voltage regulation in power supply units and its effect on the filter condensers.)

R383 Hitchcock, R. C. Designing fixed resistors. *QST*, **12**, pp. 29–32; April, 1928.

(Chart is given for rapid calculation of resistances of various kinds and sizes of wire together with safe current rating of a resistor.)

R384.1 Colebrook, F. M. Description of a valve wavemeter with a

range of 10 to 20,000 meters. *Experimental Wireless* (London), **4**, pp. 721–25; Dec., 1927.

(Precision frequency meter independent of tube variations.)

R384.1 Reed, M. The suppression of parasitic oscillations in valve circuits. *Experimental Wireless* (London), **4**, pp. 725–32; Dec., 1927.

(Application to heterodyne frequency meter.)

R384.1 Griffiths, W. H. F. Notes on the accuracy of variable air condensers for wavemeters. *Experimental Wireless* (London), **4**, pp. 754–57; Dec. 1927.

(Requirements for a condenser for use in precision frequency meter.)

R384.1 Griffiths, W. H. F. The accuracy and calibration permanence of variable air condensers for precision wavemeters. *Experimental Wireless* (London), **5**, pp. 63–74; February, 1928.

(Discussion of condenser construction as to errors introduced by stray capacities and their elimination.)

R385.5 Jakowleff, A. J. Die Berechnung der akustischer Eigenschaften des Kondensatormikrophons (calculation of the acoustical qualities of a condenser microphone). *Zeitschrift für Hochfrequenztechnik*, **30**, p. 151; Nov., 1927.

(Theory and operation of the condenser microphone.)

R386 Replogle, D. E. and Millen, J. The final capacity in a 2-section low frequency filter. *QST*, **12**, pp. 36–38; February, 1928.

(Quantitative results given of what effect changes in various condensers have on performance of filter circuit in B eliminators.)

R386 Wagner, K. Kettenleiter und Wellensiebe (filters). *Elektrot-Nachrichten Technik*, **5**, pp. 1–17; January, 1928.

(Theoretical application of filters to electrical communication.)

R386 McMeen, S. G. Filters. *Radio* (San Francisco), **10**, pp. 22–23; March, 1928.

(Explanation of filters. Chart given for the design of inductance coils with iron cores.)

R386 Replogle, D. E. Notes on the design of iron-core reactances which carry d.c. *QST*, **12**, pp. 23–27; Apr., 1928.

(Low pass type of filter for A and B battery substitutes described. Use of this type of filter for transmitting set plate supply.)

R387.1 Mason, R. B. The shielding efficiency of metals. *QST*, **12**, pp. 23–27; February, 1928.

(Measurements made of aluminum at radio frequencies show that value as shield can be predicted from its conductivity.)

R387.7 Walmsley, T. Notes on the design of radio insulators. Proc. I.R.E., **16**, pp. 361–72; March, 1928.

(Information on design of insulators used for radio transmission purposes.)

R388 Improved Duddell oscillograph outfit. *Jnl. Scientific Instruments* (London), **5**, pp. 103–107; March, 1928.

(Compact portable form of oscillograph. Applications in connection with electrical engineering practice.)

R388 Bedell, F. and Reich, H. J. The stabilized oscilloscope. *Radio Engineering*, **8**, pp. 17–20; April, 1928.

cathode-ray oscillograph with linear time axis—List of references included.)

R 400. Radio Communication Systems

R402 Grzybowski, W. W. Some investigations of short waves at Nijni-Novgorod. *QST*, 12, pp. 9–14; April, 1928.

(Description of apparatus and experimental work on high frequencies in the laboratory at Nijni-Novgorod, Russia.)

R412 Robinson, E. H. Some experiments with side band telephony on short waves. *Experimental Wireless* (London), 4, pp. 715–21; December, 1927.

(Advantages of side band transmission for frequencies above 1500 kc.)

R413 Peterson, E. and Keith, C. R. Grid current modulation. Bell System Technical *Jnl.*, 7, pp. 106–39; Jan., 1928.

(Application of grid current modulation in an experimental carrier telephone system. Tubes, filters and transformers discussed.)

R431 Armstrong, E. H. Methods of reducing the effect of atmospheric disturbances. Proc. I.R.E., 16, pp. 15–29; January, 1928.

(Balanced receiving system using difference between amplitude of strays and signal.)

R 500. Applications of Radio

R512 Gill, T. H. and Hecht, N. F. G. Rotating loop radio transmitters and their application to direction finding and navigation (Abstract of paper read before Wireless Section, Institute Elec. Engrs., London, on Jan. 4, 1928). *Experimental Wireless* (London), 5, pp. 85–88; Feb., 1928.

(Method of directional transmission developed whereby the direction finding equipment is eliminated on the aircraft and difficulties are reduced.)

R512 Smith-Rose, R. L. and Chapman, S. R. Some experiments on the application of the rotating beacon transmitter to marine navigation (Abstract of paper read before Wireless Section, Institute Elec. Engrs., London, on Jan. 4, 1928). *Experimental Wireless* (London), 5, pp. 88–90; Feb., 1928.

(Results of tests using rotating beacon transmitter for transmissions over land and sea. Beacon was calibrated.)

R512 Smith-Rose, R. L. A theoretical discussion of various possible aerial arrangements for rotating beacon transmitters (Abstract of paper read before Wireless Section, Institute Elec. Engrs., London, on Jan. 4, 1928). *Experimental Wireless* (London), 5, pp. 90–92; Feb., 1928.

(Three antenna arrangements for the rotating beacon transmitter are discussed theoretically. The uses of 3 systems of antennas, single coil, the double spaced coil, and the Adcock antenna for rotating beacons, are discussed.)

R520 Pratt, H. Radio guidance of aircraft. *Radio* (San Francisco), 10, pp. 19–20; Feb., 1928.

(Test flights to determine night and day variations in direction as given by crossed-coil beacon located in mountainous region.)

R520 Mitchell, W. G. W. London's new airport—Wireless the pilot of our airways. *Wireless World & Radio Review*, 22, pp. 130–32; Feb. 8, 1928.

(Description of new airdrome and receiving apparatus used for direction finding work.)

R520 Fassbender, H. Laboratorien und Forschungsarbeiten der Funkabteilung der Deutschen Versuchsanstalt fur Luftfahrt

in Berlin—Adlershof (Laboratories and research work of Radio Division of Germany's experimental Laboratories for aeronautics in Berlin—Adler's field). *Zeitschrift für Hochfrequenztechnik*, **30**, pp. 173–176; Dec., 1927.

(Description of laboratories and radio apparatus used on airplanes in the test work carried out at Adler's field.)

R520 Linsmayer, R. Die drahtlose Einrichtung an Bord des A28 (Arrangement of wireless apparatus on board the plane A28). *Elektrotechnik und Massachinenbau* (Die Radiotechnik), pp. 23–26; March, 1928.

(Description of radio receiving and transmitting apparatus on the airplane.)

R520 Smith-Rose, R. L. Note on a special dial for time pieces to be used with rotating wireless or other beacons. *Jnl., Scientific Instruments* (London), 5, pp. 93–96; March, 1928.

(Description of especially designed compass card dials for watches and chronographs used in connection with radio beacons.)

R520 Smith-Rose, R. L., and Chapman, S. R. Some experiments on the application of the rotating beacon transmitter to marine navigation. *Jnl.* I.E.E. (London), **66**, pp. 256–69; March, 1928.

(Results of test using rotating beacon transmitters for transmissions over land and sea. Beacon was calibrated.)

R520 Gill, T. H. and Hecht, E. S. Rotating loop radio transmitters and their application to direction finding and navigation. *Jnl.* I.E.E. (London), **66**, pp. 241–55; March, 1928.

(Method of directional transmission developed whereby the direction finding equipment is eliminated on the aircraft.)

R520 Smith-Rose, R. L. A theoretical discussion of various possible aerial arrangements for rotating beacon transmitters. *Jnl.* I. E. E. (London), **66**, pp. 270–79; March, 1928.

(The use of three systems of antennas; single coil, the double spaced coil and the Adcock antenna for rotating beacons is discussed.)

R531.2 Citizens' radio amateur call book. Published by Citizens' Radio Call Book Co., 508 So. Dearborn St., Chicago, Ill.

(Contains calls of commercial land and ship stations; amateur calls both foreign and domestic; special short wave stations—This company also issues separate book listing only broadcasting station calls).

R531.2 Short wave transmissions. *Radio Broadcast*, **13**, pp. 44–46; May, 1928.

(List of stations throughout the world working below 100 meters.)

R533 Tätz, P. Signalübertragung auf fahrende Züge mittels Wechselstrominduktion und Resonanz (signal transmission to moving trains by means of a.c. induction and resonance) *Telefunken Zeitung*, **11**, pp. 70–78; October, 1927.

(Description of apparatus used and experimental results.)

R533 Saglio, R. Receptions radiotelephoniques sur trains en marche (radio telephone reception on moving trains). *L'Onde Electrique*, **6**, pp. 589–602; Dec., 1927.

(Tests made by railroad company in France on reception of radio concerts from Eiffel Tower.)

R536 Eve, A. S. and Keys, D. A. Geophysical methods of prospecting. Bureau of Mines Technical Paper No. 420. Obtainable for 10 cents per copy from the Superintendent of Documents, Government Printing Office, Washington, D.C.

(A brief and elementary account of the principles involved including applications of radio. A short bibliography.)

R550 Dreher, C. Broadcast control operation. PROC. I.R.E., 16, pp. 498–512; April, 1928.

(Considerations of audio-frequency elements of broadcast control system discussed. Methods of measuring energy levels, equalizing lines, etc. Coordinative and regulative functions of technical staff of broadcast system, precaution against breaks in program continuity discussed.)

R550 Eckersley, P. P. The design and distribution of wireless broadcasting stations for a national service. *Experimental Wireless* (London), 5, pp. 189–97; April, 1928.

(The history of the development of British Broadcasting Co. stations is traced; experimental station at Daventry is described.)

R582 Schriver, O. Über Verstärkung in der Bildtelegraphie (On amplifiers for picture telegraphy). *Telefunken Zeitung*, 11, pp. 78–84; Oct., 1927.

(Construction of amplifying apparatus.)

R582 Rowe, G. C. B. Television comes to the home. *Radio News*, 9, pp. 1098–1100; April, 1928.

(Explanation of Alexanderson transmitter and description of television short wave receiver.)

R594 Fortschritte im elektrischen Nachrichtenwesen im Jahre 1927 im Deutschland (Progress in electrical communication in Germany during 1927). *Electrot-Nachrichten Technik*, 5, pp. 33–39; January, 1928.

(Report of work along electrical lines including radio.)

R599 Deloraine, E. M. La station radiotelephonique de Prague (Radiotelephone station of Prague). *L'Onde Electrique*, 7, pp. 21–32; January, 1928.

(Description of broadcasting station in Prague, Czechoslovakia.)

R 800. NON-RADIO SUBJECTS

510 Barclay, W. A. Dimensionality in wireless equations. *Experimental Wireless* (London), 5, pp. 211–13; Apr., 1928.

(Points out practical use of the concept of dimensionality in checking the accuracy of equations developed in theoretical work, especially in the radio field.)

537.1 Howe, G. W. O. Some further problems in potential difference. *Experimental Wireless* (London). 5, pp. 175–78; Apr., 1928.

(Treats some simple problems in the electric potential of dielectric rings. The questions which are considered are fundamental to a proper understanding of electric circuits.)

537.65 Cady, W. G. Bibliography on piezoelectricity. PROC. I.R.E., 16, pp. 521–35; April, 1928.

(List of publications, patents and books on piezoelectricity up to beginning of 1928.)

621.313.7 Copper oxide rectifier. *Experimental Wireless* (London), 5, pp. 1–2; January, 1928.

(Description and characteristic curve of rectifier.)

GEOGRAPHICAL LOCATION OF MEMBERS ELECTED

June 6, 1928

Transferred to the Fellow grade

New Jersey	Boonton, Radio Frequency Laboratories	Ballantine, Stuart
	Boonton, Radio Frequency Laboratories	Hull, Lewis M.

Transferred to the Member grade

Illinois	Chicago, 7620 Phillips Avenue	Falknor, Frank B.
Kansas	Fort Leavenworth, Box 506	De Remer, C. W.
Maryland	Baltimore, 3100 St. Paul Street	Wheeler, Harold A.
Massachusetts	Cambridge, Massachusetts Institute of Technology	Bowles, Edward L.
	Winchester, Appalachian Road	Browning, Glenn H.
Michigan	Detroit, 504 Commerce Bldg.	Brown, Jesse E.
	Detroit, 504 Commerce Bldg.	McNary, James C.
New York	Little Neck, L. I., 4310 Bay View Avenue	Di Blasi, John
	Mount Vernon, 2 Park Avenue	Houck, Harry W.
	New York City, Radio Corporation of America, 233 Broadway	Burchard, J. C.
	New York City, 233 Broadway, Room 2001	Adams, Ira J.
	New York City, Radio Corporation of America, 66 Broad St.	Finch, J.
Wisconsin	Madison, University of Wisconsin, Sterling Hall	Terry, Earle M.

Elected to the Member grade

Connecticut	East Hartford, 400 Burnside Avenue	Randall, J. Clayton
Illinois	Chicago, Congress Hotel, c/o W. E. & M. Co.	Evans, Walter C.
New York	New York City., Bell Tel. Labs., 463 West Street	Marrison, W. A.
France	Paris, 16e, 58, Rue Michel Ange	Cheftel, A. M.

Elected to Associate grade

Arkansas	Little Rock, 1000 State Street	Hofslatter, F. H.
California	Los Angeles, 5157 Arlington Street	Barlow, Roy G.
	Los Angeles, 531 S. Mariposa Avenue	Eldridge, Robert H.
	Marshal, c/o Radio Corporation of America	Wells, Wm. Bruce
	Palo Alto, 219 Hawthorne Avenue	Whittern, Ray
	San Diego, 535 West University Avenue	Conaughty, Robert B.
	San Francisco, Pacific Gas & Electric Co., 245 Market St.	Benson, F. S.
	San Francisco, 202 Green Street	Farnsworth, Philo F.
	Sam Francisco, 742 Clement Street	Maxwell, John F.
	San Jose, 235 San Carlos Street	Reynolds, F. T.
Colorado	Arvada	Larsen, Archie M.
Connecticut	New London, 216 Pequot Avenue	Helgren, Diva M.
	Plainville, 9 Whiting Street	Jones, H. Garfield
Georgia	Tignall	Talkington, Fletcher F.
Illinois	Chicago, 205 North Crawford Avenue	Kobberup, Jack R.
	Chicago, 545 North Central Avenue	Morey, W. J.
	Evanston, 1835 Dodge Avenue	Hill, James H.
	Milford	Osborn, Paul I.
Indiana	Fort Wayne, 1257 Lake Avenue	Dreisbach, Robert H.
	Richmond, The Star Piano Co.	Soule, Harold
	Valparaiso, 360 Locust Street	Alexander, Donald H.
	Valparaiso, c/o The Dodge Institute	Crews, J. H.
	Valparaiso, 507 Union Street	Ferrin, Sidney E.
Iowa	Sioux City, 3605-5th Avenue	Coates, Frank M.
Kansas	Atchison, 111 E. Atchison Street	Arthur, Ralph L.
Maryland	Mt. Ranier, 3509 R. I. Avenue	Gordon, Raymond A.
Massachusetts	Brighton, 157 Foster Street	Sylvester, John C.
	Cambridge, 1558 Massachusetts Avenue	Weare, John
	Dorchester, 32 Wilder Street	Chessler, Maxwell A.
	Newburyport, Box 544	Scott, Gilbert H.
Michigan	East Lansing, P. O. Box 612	Sabbaugh, Elias M.
	Lansing, 121 Clifford Street	Carr, I. E.
Missouri	Kansas City, 1820 Grand Avenue	Rode, Harry A.
	St. Louis, 806 Hickory Street	Garvey, Arthur
	Springfield, Martin Bros. Piano Co.	Ward, G. Pearson
New Jersey	Atlantic City, Million Dollar Pier	Jones, H. Rossiter
	Hackettstown, P. O. Box 55	Mitchell, George G. Jr.
	Jersey City, 96 Waldo Avenue	Smith, Percy de Willard
	Palmyra, 505 Leeoney Avenue	Thomas, Harry Elliot
	Towaco	Hence, P. D., Jr.
	Trenton, R. F. D. No. 36, 818 President Ave.	Burroughs, Irving D.

New York	Bath	Loveless, Lawrence M.
	Brooklyn, 79 Seigel Street	Secan, Harry
	Buffalo, 31 Rugby Road	Fox, John E.
	Buffalo, 100 Taunton Place	Hobbs, Frank B.
	Buffalo, 236 Barton Street	Miller, George H.
	New City, Rockland County	Doellner, Le Roy J.
	New York City, 240 W. 52nd Street	Elias, Morris I.
	New York City, 1458 Wilkins Avenue	Goldberg, Harry
	New York City, National Broadcasting Co.	Graveson, George L.
	New York City, 270 Park Avenue	Keim, Llewellyn B.
	New York City, 211 West 107th Street	Montgomery, A. Peerse
	New York City, 233 Broadway	Norton, Frederick A.
	New York City, 66 West 87th Street	Proskauer, Julien J.
	New York City, 263 West 68th Street	Valesio, Mario J.
	Riverhead, L. I., Radio Corp. of America	Wickizer, Gilbert S.
	Rochester, 186 Clinton Avenue North	Reddy, Walter G.
	Schenectady, 1 Fairview Avenue	Lang, Walter T.
	Schenectady, 21 Governor's Lane	Langdon, G. G.
Ohio	Cleveland, 3102 Chestnutdale Avenue	Glatz, Henry
	Cleveland, 1062 Thrush Avenue	Simpson, Paul A.
	Cleveland, 1584 East 43rd Street	Smith, F. J.
	Dayton, 3621 West Hillcrest Avenue	Petry, C. A.
	Marietta, 207 Curtis Terrace	Muscari, Pietro J. G.
	Youngstown, 1019 Hawthorne Street	Phillips, R. G.
Oklahoma	Bartlesville, 709 Wyandotte Avenue	Miller, Erdene K.
	Oklahoma City, 308 West Second Street	Allen, Roy
Oregon	Portland, 1350 East 36th Street	Dixon, Ashley C.
Pennsylvania	Churchville	Hinkel, Walter A.
	Grove City, 513 State Street	Boundy, Glenn G.
	Harrisburgh, 53 North 17th Street	Rogers, Clifford H.
	Highland Park, 141 N. Madison Avenue	Greenwald, Arthur A.
	Philadelphia, 13th and Green Streets	Gryning, John F.
	Scranton, 821 Quincy Avenue	Alexander, F. S.
	Wesleyville, 3523 Fremont Street	Dutton, George I.
	Wilkinsburgh, Forest Hills Road	Ilrey, David
Texas	Dallas, 912 Commerce Street, Room 500	Evans, W. J.
	Dallas, 1610 Commerce Street	Green, J. Moore
Utah	Murray, 5670 South 6th West Street	Nichols, Harry W.
	Salt Lake City, 2931 South 23rd East Street	Hawkins, John B.
Washington	Seattle, 540 North 82nd Street	Austin, Leslie C.
	Seattle, 609 Washington Boulevard	Brott, F. J.
	Seattle, 3209-15th Avenue South	Hockett, Paul J.
	Seattle, 5713-5th Avenue South	Richards, John
West Virginia	Charleston, 1021½ Bigley Avenue	Stalnaker, Burr
Wisconsin	Madison, University of Wisconsin, Y. M. C. A.	Cheng, L. Y.
	Osseo, Box 12	Nelson, Orrin B.
Canada	Ontario, Belleville, Box 40 B	Anderson, J. F.
	Ontario, Belleville, 155 Ann Street	Gerrie, Wm. H.
	Ontario, Burlington, Box 575	Fletcher, Henry J.
	Ontario, London, 462 Dufferin Avenue	Graham, Burwell
	Ontario, London, 185 Dundas Street	Gurd, Ronald H.
	Ontario, London, 493 King Street	Howe, A. E.
	Ontario, London, Crawford Piano Co.	Underell, Charles
	Ontario, Toronto, 139 Snowden Avenue	Gadsby, S. J.
	Ontario, Toronto, 355 King West	Jackson, Leslie
	Ontario, Toronto, 14 Ridley Gardens	Mc Queen, W. T.
	Ontario, Toronto, 124 Richmond Street West	Patterson, C. F.
	Ontario, Toronto, 579 Spadina Avenue	Russell, W. G.
	Ontario, Toronto, 125 Pape Avenue	Smith, B. J.
	Ontario, Toronto, 285 Jarvis Street	Van Sickle, Melvin
	Quebec, Westmount, 575 Roslyn Avenue	Henderson, John T.
England	Burnley, Park Lane, Ightenhill Park Lodge	Jackson, Willie
	Cheltenham, 52 Winstonian Road	Brown, William G.
	Cornwall, Bodmin Beam Station	Woodhead, H. A.
	Durham, Sherburn Co., High Pittington, Hazelhurst	Maitland, James L.
	Lancaster, Bolton, Deane, 20 Platt Hill Avenue	Smith, S. Norman
	London, Wandsworth Common, 3, Ouseley Road	Lawler, L.
	London, S. W. 1, 6 Pall Mall c/o Lloyds Bank	Thomspson, F. S.
	Somerset, Bridgewater, G. P. O. Beam Station	Rees, Hubert S.
	Somerset, Bridgewater, Taunton Road	Ware, William
	Wallsend-on-Tyne, 17 Woodbine Avenue	Ogg, J. G.
India	Bangalore, Indian Institute of Science	Rangachari, T. S.
	Madras, Madras Club	Moone, Albert J. L.
New Zealand	Wellington, 39 Scarborough Terrace	Roberts, R. V.
South Africa	Durban, 146 Umbile Road	Allaway, George N.
West Australia	Perth, Mt. Hawthorne, 36 Fairfield Street	Elliott, Frank E.
	Perth, 5th Avenue, Inglewood	Coxon, Walter E.

Elected to Junior Grade

Colorado	Arvada, Box 73	Slusher, Charles A.
Illinois	Chicago, 455 Belden Avenue	Jobe, Allen C.

Indiana	Lafayette, 2540 Cason Street	Ebbeler, Donald H.
	Valparaiso, 451 Greenwich Avenue	Barnett, Louis W.
	Valparaiso, Dodge Radio Institute	McDuffee, Thomas
	Valparaiso, 556 Locust Street	Mooney, Charles L.
	Valparaiso, Dodge Radio Institute	Trubey, Lester E.
Kansas	Belleville	Douglas, Ralph S.
	Belleville, 1313-21st Street	Reese, Wilburn A.
Massachusetts	Cambridge, 45 Bow Street, Randolph 48	Johnson, Montgomery
	Dorchester, 18 Longfellow Street	Barry, Francis J.
Minnesota	Minneapolis, 212 Walnut Street, South East	Barnes, James C.
Oklahoma	Tulsa, 918 East 8th Street	McNally, Eugene Clark
Pennsylvania	Uniontown, Taylor Place	Crow, John B.
Texas	Amarillo, 512 West 7th Street	Wimberly, W. Ben
Canada	British Columbia, Victoria, 832 Linkless Avenue	Thompson, J. H.
	Ontario, Toronto 13, 11, Avonlea Boulevard	Innes, Ronald G.
	Ontario, Toronto, 257 Ossington Avenue	Orr, Albert
Scotland	Dundee, 22 Nelson Street	Edwards, R. M.

Take the Advice of Leading Radio Service Organizatons —

Play Safe With PARVOLTS!

Mr. McDonell says: "Our PARVOLT display board is very useful, for we often show our clients how these condensers are made."

IF you want the real truth about condensers go to an organization that builds, services and repairs every type of radio receiver and power supply unit.

Mr. Frank McDonnell of Rossiter, Tyler & McDonell, says:

"We think so well of ACME PARVOLT *Condensers that we have samples constantly on display for all clients to see. Those of our customers who know radio also know that PARVOLTS are thoroughly reliable. We like our clients to realize that we use the best in radio."*

Should a condenser blow out, many dollars would be lost in ruined tubes, transformers, chokes and other parts. The experience of the nationally known house of Rossiter, Tyler & McDonell should be a good guide for other builders and service men to follow. Don't take chances with condenser breakdown. Play safe with ACME PARVOLTS.

Made by THE ACME WIRE CO., New Haven, Conn., manufacturers of magnet and enameled wire, varnished insulations, coil windings, insulated tubing and radio cables.

ACME PARVOLT FILTER CONDENSERS—all standard mfg. capacities for 200, 400, 600, 1000, and 1500 Volt D.C. requirements. Uniform height and width for easy stacking. Also in complete housed blocks for important power supply units such as Thordarson, Samson and others.

ACME PARVOLT BY-PASS CONDENSERS in all standard mfd. capacities and all required working voltages.

ACME PARVOLT CONDENSERS

Made by the Manufacturers of

ACME CELATSITE HOOK-UP WIRE

ENAMELED AERIAL WIRE
Enameled copper wire in both stranded and solid types. Also Acme Lead-ins, Battery Cables, Indoor and Loop Aerial Wire.

CELATSITE FLEXIBLE and SOLID
For all types of radio wiring. High insulation value; non-inflammable. 10 colors.

ACME SPAGHETTI
A superior sombre tubing for all practical radio and other electrical requirements. Supplied in 10 colors.

Durham

Metallized Resistors for Every Radio Power Purpose—

Now, after three years of experiment and research, International Resistance Co. offers a complete line of resistances for all types of receivers, power amplifiers and accessory radio devices at new low costs which represent important savings.

Durham Resistors are supplied in ranges from 500 Ohms to 10 Megohms, while Durham Powerohms range from 1 to 50 Watts and are supplied with every practical type of tip as illustrated. All are constructed upon the well-known Durham Metallized principle which has been approved in every type of service by the most important set and amplifier manufacturers in the country.

As for years past with Durham Resistors, these modern Powerohms are guaranteed for accuracy and absolute dependability.

Samples and full data with accurate operating curves together with prices, supplied upon request.

1. Durham Resistors—500 Ohms to 10 Megohms; standard brass end tip, mould or pigtail type.
2. Durham Grid Suppressors—250 Ohms to 3000 Ohms in steps of 100; standard brass end tip.
3. Durham Powerohm—1 Watt; 250 to 1,000,000 Ohms; standard brass end tip or pigtail type.
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5. Durham Powerohm—2½ Watts; 500 to 250,000 Ohms; knife-end type.
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9. Durham Powerohm—10 Watts; 250 to 250,000 Ohms; soldered end tapped and screw-end type.
10. Durham Powerohm—25 Watts; 250 to 250,000 Ohms; soldered and tapped.
11. Durham Powerohm—50 Watts; 250 to 250,000 Ohms; soldered and tapped.
12. Durham Mounting supplied in various lengths to carry any required number of Powerohms where quick change of resistance is necessary.

INTERNATIONAL RESISTANCE COMPANY
2½ South 20th Street, Philadelphia, Pa.

DURHAM METALLIZED

RESISTORS & POWEROHMS

Behind the POLYMET *Trade Mark*

Polymet TRADE MARK

QUALITY SERVICE DEPENDABILITY

The natives of an obscure Scottish isle specialize in weaving the finest of woolens. Shipments can be made only when a chance vessel calls. Quality? Yes, but delivery lacks dependability.

A one-time manufacturer of very fine automobiles is no longer in business. Again *Quality*, but owners lack service.

Behind the Polymet seal there is unquestioned *Quality*, and something more—the Polymet organization, insuring the utmost in *Service* and *Dependability*.

Send for the Polymet Catalogue.

POLYMET MANUFACTURING CORP.
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POLYMET PRODUCTS

AmerTran Push-Pull Amplifier—First stage AmerTran DeLuxe and second stage AmerTran Push-Pull for two Power Tubes. AC or DC sets, 171 or 210 type tubes. Price, east of Rockies—less tubes, $60.00.

AMERTRAN

Quality Radio Products—the Basis of Natural Reproduction

EVERY year the importance of radio reproduction has advanced until now, the question among radio enthusiasts has changed from "How much distance can you get?" to "How good is your tone quality?

The audio amplifier is the basis of tone quality. Since broadcasting came into being, AmerTran products have been the Standards of Excellence for Radio Reproduction. How many times have you heard the question asked, perhaps asked it yourself, "Is it as good as AmerTran?" As long as that question is asked, there can be no doubt as to the standing of AmerTran products in the radio industry.

The products shown on this page are but a few of the thirty odd AmerTran devices in the field of radio reproduction, each of which has attained the degree of perfection necessary to be introduced as an AmerTran product. The facilities of our engineering department are at the service of every one interested in better radio reproduction. We will answer to the best of our ability any question in the audio or power fields.

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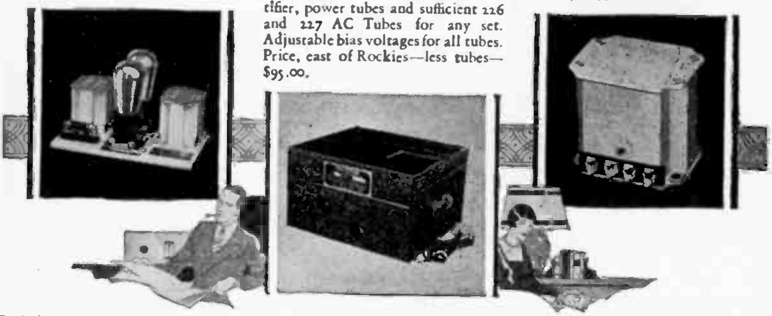
Transformer Builders for more than 28 years

220 EMMET ST., NEWARK, N. J.

AmerTran Push-Pull Power Stage—completely wired with input transformer and a choice of 4 output transformers depending on speaker and power tubes. Price, east of Rockies—less tubes—$36.00.

AmerTran ABC Hi-Power Box—500 volts DC plate voltage, current up to 110 ma; AC filament current for rectifier, power tubes and sufficient 226 and 227 AC Tubes for any set. Adjustable bias voltages for all tubes. Price, east of Rockies—less tubes—$95.00.

AmerTran DeLuxe Audio Transformer, Standard of Excellence; each $10.00.



Push-Pull Amplifier, ABC Hi-Power Box and Push-Pull Power Stage licensed under patents owned or controlled by RCA and may be bought complete with tubes.

Radio - Is - *BETTER* - With - Dry - Battery - Power

made to run the *full* race!

ANY horse can make a good start . . . . . . But it takes real stamina to *finish!* ¶So it is with batteries. *Staying* power is the quality to look for—unfailing power over a long period of service. Millions prefer Burgess *Chrome* Batteries for just this reason. They hold up . . . . . . They *last.* ¶Next time, buy black and white striped Burgess *Chrome* Batteries. You are certain to get longer and better service for your money.

Chrome —the preserving element used in leather, metals, paints and other materials subject to wear, is also used in Burgess Batteries. It gives them unusual *staying* power. Burgess *Chrome* Batteries are patented.

Ask Any Radio Engineer

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BURGESS BATTERIES

MERSHON AMRAD CONDENSER

While the Amrad Mershon Condenser is easily adapted to practically any radio circuit—it is prominent in the eyes of the radio engineering world today, because of its peculiar efficiency in connection with new electrical sets, and the problems presented by a necessity for tremendous capacity in small space.

1. Self healing in case of puncture.
2. Lower cost per microfarad.
3. One third as large as paper condensers of the same capacity.
4. Extremely rugged construction.
5. Unaffected by changes in temperature or by moisture.

Peak voltage 400 V.D.C.

Operating voltage 300 V.D.C.

Copper can is always negative—anodes are always positive.

Supplied in a variety of sizes that enable it to be readily employed whatever the requirement may be.

The AMRAD Corporation
Medford Hillside, Mass.

J. E. Hahn
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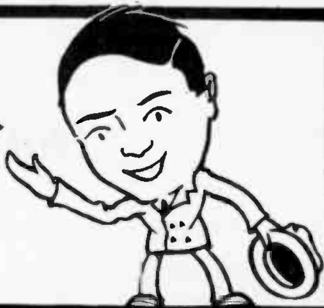
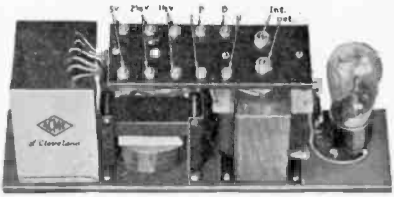
Send for free copy of our books on the Mershon Condenser, including special engineering pamphlet showing typical hook-ups, etc.

The Amrad Corporation owns the exclusive license and manufacturing rights of the Mershon Condenser under the patents of Col. Ralph D. Mershon.

ACME CLEVELAND OHIO



POWER PACK



MANUFACTURERS MODEL POWER PACK AEC
FOR AC TUBES USING UX280 OR CX380 TUBES
WIDTH 3 INCHES, LENGTH 12 INCHES,
HEIGHT 5¼ INCHES
CAPACITY 40 MILLS. AT 160-180 VOLTS
OPERATES ON 110 115 VOLTS, 50-60 CYCLES

Specifications of the above are as follows:

5-UX 226 or CX 326 Tubes
1-UY 227 or CX 327 Tube
1-UX 171-A Tube
"C" Voltage 4½ and 40 volts.

Investigate this neat, compact, quiet device for supplying A, B & C Power to convert present D.C. battery operated sets to A.C. operation, using the new A.C. tubes.

Visit our Booth No. 54 or Demonstration Room 524-A at the R.M.A. Exposition and see this Pack in operation.

Power Packs, Chokes and Transformers can be supplied to meet your exact requirements by our experienced Engineering Department.

The Acme Electric and Manufacturing Company
1653 Rockwell Avenue — Cleveland, Ohio

Also Manufacturers of famous Acme Radio Power Units

MEMBER R.M.A.

Established in 1917

Decade Condenser

Type 219

The dial switch type of control greatly facilitates the manipulation of variable apparatus. The type 219 Decade condensers offer a variable capacity using this principle.

These condensers find a use in filter networks and in variable frequency oscillators, wherever a condenser system of large and rapidly variable capacity is required.

Described in Bulletin 1050-I.

Type 219-F. Price $40.00
- Ten 0.01 MF steps
- Ten 0.1 MF steps

Type 219-G. Price $60.00
- Ten 0.001 MF steps
- Ten 0.01 MF steps
- Ten 0.1 MF steps

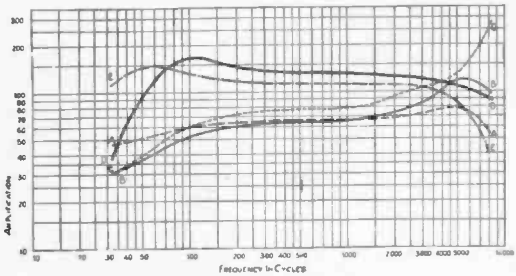
GENERAL RADIO COMPANY

Manufacturers of Electrical and
Radio Laboratory Apparatus

30 STATE STREET CAMBRIDGE, MASS.

NEW!

Audio Transformers Public Address Amplifier Short Wave Kit



S-M 225 Audio Transformer—See Curve E

SILVER-MARSHALL has ready new audio transformers giving double the amplification of the best existing types, a far better frequency characteristic, and practical elimination of hysteretic distortion. Curve "D" above illustrates the performance of a pair of the new small S-M 255 and 256 transformers listing at $6.00 each, as compared to three pairs of $8.00 to $10.00 transformers on the open market. It tells the story of doubled amplification and improved bass amplification. Curve E is for a pair of S-M 225 and 226 transformers, listing at $9.00 each. These new transformers are available to manufacturers at surprisingly low prices. At the June R. M. A. trade show S-M will demonstrate a comparison amplifier which audibly proves the superiority of the new $6.00 transformers over any standard existing types.

Type 685 Public Address Unipac

For high quality high volume coverage of crowds of 2,000 to 10,000 people with one to twelve speakers, as in theaters, churches, auditoriums, or out-of-doors, the new S-M Unipac is ideal. It is a self-contained light-socket power amplifier for radio, record pick-up or microphone input, using one UY227, one UX226, one UX250, and two UX281 Radiotrons. Type 685 Unipac, factory wired and assembled, is priced at $160.00, less tubes and accessories, or, in kit form, ready to assemble, $124.00.

Screen Grid Short Wave Kits

The new S-M "Round the World Four" and "Round the World Adapter" are two non-radiating short wave receiver kits housed in aluminum shielding cabinets, and tuning from 17.4 to 204 meters with four plug-in coils. They are the first sets to employ R. F. amplification at short waves with but one tuning dial. Price, 730 four tube kit, complete with cabinet $51.00; 731 two tube adapter $36.00; 732 essential kit containing coils, condensers and R. F. chokes, $16.50.

SILVER-MARSHALL, Inc., 838 W. Jackson Blvd.
CHICAGO, U. S. A.

EVERY FACILITY FOR EXPERT RESEARCH

THE Research and Development Laboratory of Automatic Electric Inc., manufacturers of Strowger Automatic condensers, is one of the most completely equipped of its kind in the world. The use of its many sensitive and complex instruments enables the development engineers to *know exactly* rather than to guess what occurs in any electrical circuit at any time.

The design and manufacture of satisfactory condensers for radio purposes is dependent upon such exact scientific knowledge. The reliability and efficiency which have become synonymous with the name Strowger in automatic telephony, are incorporated to a like extent in the line of filter, by pass and high voltage condensers now available to the radio trade. The company's research facilities are always at the disposal of any interested parties requiring condensers of special design for special purposes.

[*See that your radio set is equipped with Strowger Automatic condensers*]

A.G. BURT, JR.

1033 WEST VAN BUREN ST.
CHICAGO, U. S. A.

REPRESENTING

STROWGER AUTOMATIC CONDENSERS

MADE BY
Automatic Electric Inc.
CHICAGO, U.S.A.

When writing to advertisers mention of the PROCEEDINGS *will be mutually helpful.*

Consider First—
The Volume Control

THE volume control of a radio set is one of the parts most used and subjected to the most wear. Care must be taken to choose the type that will give longest, trouble-free service—a type that will not introduce noise to interfere with the quality of reception after a short period of service.

Centralab Volume Controls have a patented rocking disc contact that eliminates all wear on the resistance material. This feature adds to the smoothness of operation in that a spring pressure arm rides smoothly on the disc and NOT on the resistance. The bushing and shaft are thoroughly insulated from the current carrying parts. This simplifies mounting on metal panel or sub base and eliminates any hand capacity when the volume control is in a critical circuit. Full variation of resistance is obtained in a SINGLE TURN of the knob.

Plus these exclusive features, Centralab has carefully studied every volume control circuit and has built-up tapers of resistance to fit each application. These specific resistances are an assurance of a control that will smoothly and gradually vary the volume from a whisper to maximum—No sudden cut-offs on distant signals—No powerful locals creeping through when control is set at zero.

Write for folder of applications

Centralab

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CENTRAL RADIO LABORATORIES

Keefe Ave. Milwaukee, Wis.

A CENTRALAB VOLUME CONTROL IMPROVES THE RADIO SET

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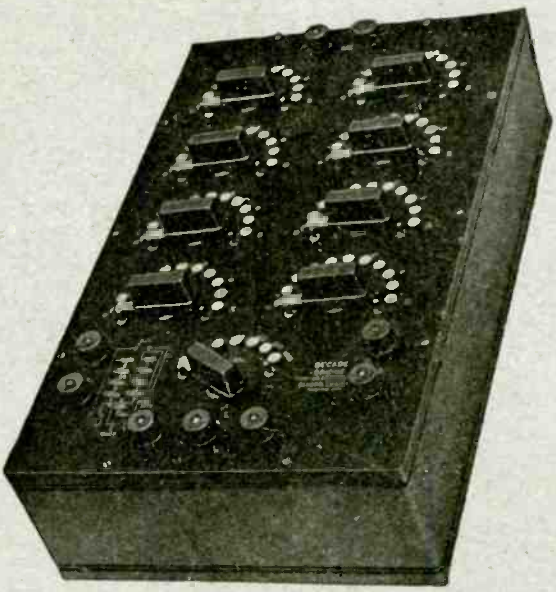
DECADE BRIDGE



Type 193 Decade Bridge

A Wheatstone Bridge using the dial-decade design.

For measurement of direct current resistance and alternating current resistance, inductance capacitance at commercial and audio frequencies.

The third resistance can be switched into either the unknown or the standard arm for inductance and capacitance measurements.

Described in Bulletin 4050-I

Price $115.00

GENERAL RADIO COMPANY

Manufacturers of Electrical and Radio Laboratory Apparatus

30 STATE STREET CAMBRIDGE, MASS.

GEORGE BANTA PUBLISHING COMPANY, MENASHA, WISCONSIN